Iron and Steel Engineer

Established 1907 as Proceedings of A. I. & S. E. E.

JOHN F. KELLY, EDITOR

CONTENTS

Volume X. MARCH, 1933. Number III.

PRACTICAL METHODS FOR INDUCTIVELY HEATING SOLIDS—by Dr. E. F. Northrup, Vice President and Technical Adviser, Ajax Electrothermic Corp., Trenton, N. J. 67

DISCUSSION—PRACTICAL METHODS FOR INDUCTIVELY HEATING SOLIDS—Discussion presented by W. Dudley, Dr. E. F. Northrup, L. J. Reed, C. O. Franklin, S. B. Terry, R. R. Owen, R. N. Blakeslee, Jr., and J. W. Bates 82

THE RELEASOR—by R. J. Harry, Engineer, Alliance Machine Company, Alliance, Ohio 85

A. I. & S. E. E. CONVENTION AND EXPOSITION ANNOUNCEMENT 86

ADVANCES IN RESISTANCE WELDING MADE POSSIBLE WITH THYRATRON CONTROL—by W. C. Hutchins, Industrial Engineering Dept., General Electric Company, Schenectady, N. Y. 87

DISCUSSION—ADVANCES IN RESISTANCE WELDING MADE POSSIBLE WITH THYRATRON CONTROL—Discussion presented by Stanley Grand Girard, W. C. Hutchins, D. I. Bohn and F. S. Balke 94

ITEMS OF INTEREST 96

COMING MEETINGS AND PAPERS II

NEW USES FOR STEEL CAMPAIGN III

INDEX TO ADVERTISERS IV

Published Monthly by

Association of Iron and Steel Electrical Engineers

BOARD OF DIRECTORS—1932-1933

President, J. D. Donovan, Electrical & Mechanical Superintendent, Republic Steel Corp., Canton, Ohio.

1st Vice Pres., W. E. Miller, Electrical & Mechnical Supt., Bethlehem Steel Company, Johnstown, Pa.

2nd Vice Pres., W. H. Burr, Electrical & Mechanical Supt., Lukens Steel Company, Coatesville, Pa.

Secretary, J. A. Clauss, Chief Engineer, Great Lakes Steel Corp., Ecorse, Mich.

Past Pres., J. J. Booth, Electrical Supt., National Tube Company, Gary, Ind.

Past Pres., F. O. Schnure, Electrical Supt., Bethlehem Steel Company, Sparrows Point, Md.

Director at Large, G. R. Carroll, Electrical Supt., Jones & Laughlin Steel Corp., Aliquippa, Pa.

Honorary Director, James Farrington, Electrical Supt., Wheeling Steel Corp., Steubenville, Ohio.

Director, H. D. Esterly, Electrical Supt., Alan Wood Steel Company, Conshohocken, Pa.

Director, E. C. Marshall, Electrical Supt., Youngstown Sheet & Tube Company, East Chicago, Ind.

Director, R. F. Sanner, Assistant Electrical Engineer, Carnegie Steel Company, Duquesne, Pa.

Director, W. H. Gilbert, Assistant to Mechanical Engineer, Tennessee Coal, Iron & R. R. Co., Birmingham, Ala.

Director, J. L. Miller, Steam Engineer, Carnegie Steel Company, Youngstown, Ohio.

Director, A. D. Adams, Assistant Supt., Spang Chalfant & Company, Inc., Ambridge, Pa.

Director, P. F. Haberstick, Safety Engineer, Wheeling Steel Corp., Wheeling, W. Va.

Director, A. L. Foell, Chief Engineer, Arthur G. McKee Company, Cleveland, Ohio.

Honorary Director, E. Friedlander, Pittsburgh, Pa.

Managing Director, John F. Kelly, Empire Building, Pittsburgh, Pa.

Entered as second-class matter January 25th, 1924, at Pittsburgh, Pa., under the Act of March 3rd, 1879.
Subscription Price $5.00 per Year. Single Copy $1.00.

Coming Meetings and Papers

ASSOCIATION OF IRON AND STEEL ELECTRICAL ENGINEERS

▲

CHICAGO DISTRICT SECTION

W. A. PERRY, Chairman — A. J. WHITCOMB, Secretary

TUESDAY, APRIL 11, 1933

ELECTRIC ASSOCIATION ROOMS — 20 NORTH WACKER DRIVE, CHICAGO, ILL.

DINNER 6:30 P. M.

"RECENT DEVELOPMENTS IN CONTROL," by J. F. Headlee, Testing Engineer, Gary Works, Illinois Steel Co., Gary, Ind.

▲

PHILADELPHIA DISTRICT SECTION

C. M. THOMPSON, JR., Chairman — LINN O. MORROW, Secretary

SATURDAY, APRIL 1, 1933

ENGINEERS CLUB — PHILADELPHIA, PA.

DINNER 6:00 P. M.

GENERAL IDEAS AND DISCUSSION

"REDUCTION OF POWER COSTS BY THE USE OF MODERN EQUIPMENT, by George C. Pfeffer, Chief Electrician, Florence Pipe Foundry & Machine Co., Florence, N. J.

"EMPLOYEES SUGGESTION SYSTEMS," by Walter H. Burr, Superintendent Electrical and Mechanical Dept., Lukens Steel Co., Coatesville, Pa.

"NON-METALLIC BEARINGS," by L. F. Coffin, General Master Mechanic, Bethlehem Steel Co., Sparrows Point, Md.

"FACTORS ENCOUNTERED IN CHANGING FROM MANUAL TO AUTOMATIC CONTROL ON NINE-INCH MILL MAIN ROLL DRIVE," by G. O. Van Artsdalen, Electrical Superintendent, Henry L. Disston & Sons, Inc., Philadelphia, Pa.

There will also be papers by K. M. Raynor, N. C. Bye, R. F. Gale and others.

▲

CLEVELAND DISTRICT SECTION

A. L. FOELL, Chairman — W. W. SPANAGEL, Secretary

FRIDAY, APRIL 28, 1933

ENGINEERS CLUB — CLEVELAND, OHIO

DINNER 6:00 P. M.

"SYNCHRONOUS MOTORS FOR MAIN DRIVES."

▲

PITTSBURGH DISTRICT SECTION

J. W. BATES, Chairman — J. I. KASPARI, Secretary

SATURDAY, APRIL 22, 1933

BLUE ROOM, WILLIAM PENN HOTEL — PITTSBURGH, PA.

7:30 P. M.

"CIRCUIT INTERRUPTION BY OIL-BLAST," by D. C. Prince, Engineer, Switch Gear Dept., Philadelphia Works, General Electric Co., Philadelphia, Pa.

"SYMPOSIUM—COLD MILL PRACTICES." Meeting deferred until later date.

▲

BIRMINGHAM DISTRICT SECTION

SATURDAY, MARCH 25, 1933

W. J. DONAHUE, Chairman — J. B. LOONEY, Secretary

"STEEL MILL LUBRICATION—ITS RELATION TO ECONOMY AND SAFETY," by E. A. Harper, Lubricating Engineer, The Texas Company, Birmingham, Ala.

ADVERTISING PAGES OMITTED

Practical Methods For Inductively Heating Solids

By DR. E. F. NORTHRUP
Vice President and Technical Adviser, Ajax Electrothermic Corp., Trenton, N. J.

Presented before the Pittsburgh District Section of the A. I. & S. E. E. January 14, 1933.

Preliminary.

In the industries, metals and alloys of numerous kinds and of varied size and shape are heated below their melting point for annealing, normalizing or forging. At some stage in their fabrication practically all metals and alloys, which are not directly cast from the molten condition into final molds, require this re-heating, often to a temperature but little under their melting temperature. We shall endeavor to explain under what conditions and by what means and apparatus this may be accomplished using electric induction in a manner to meet technical and economic requirements.

When inductive heating is employed it is important to consider whether the product to be heated is magnetic or non-magnetic. If a ferrous metal or alloy is to be heated under its decalescent point, the current and equipment needed will be quite different, in general, from what is required when the final temperature is carried above the point where magnetism is lost. All non-ferrous metals and alloys of similar form and size may be treated inductively in much the same way. Incidentally, I may remark that carbon and graphite can be heated inductively in much the same manner as non-magnetic metals and the temperature can be and has been carried to a point where graphite volatilizes. I shall, however, at this time confine myself strictly to a consideration of the inductive heating of solids which are metallic.

FUNDAMENTAL PRINCIPLES WHICH UNDERLIE INDUCTIVE HEATING OF SOLIDS

I. When Metals are Non-Magnetic.

We shall use simple diagrams and physical concepts to lead us rapidly and directly to an understanding of how non-magnetic solids may be heated by induction effectively. We first consider the simple and often common case in which a solid right cylinder of non-magnetic metal is to be inductively heated by a single layer coil which surrounds it. We shall refer to the coil as the "inductor" and shall term the mass to be heated the "susceptor." In Fig. 1 is shown in vertical section, A, and in horizontal section, B, a typical case of this kind.

In general, the inductor would be made as a single layer coil. Round or flattened copper tubing which carries both current and cooling water is used.

When the inductor carries direct current, the magnetic field is sensibly uniform inside the inductor except near the ends, where the lines of force fan out. To simplify our considerations, let attention be focussed upon the zone included between two parallel planes, a-a and b-b, taken unit distance apart and at right angles to the common axis of the inductor and susceptor. (Fig. 1-A). We may then treat the magnetic field in this region as quite uniform. Since the susceptor is assumed as being entirely non-magnetic, the distribution of the field, with direct current in the inductor, is undisturbed by inserting the susceptor in the inductor.

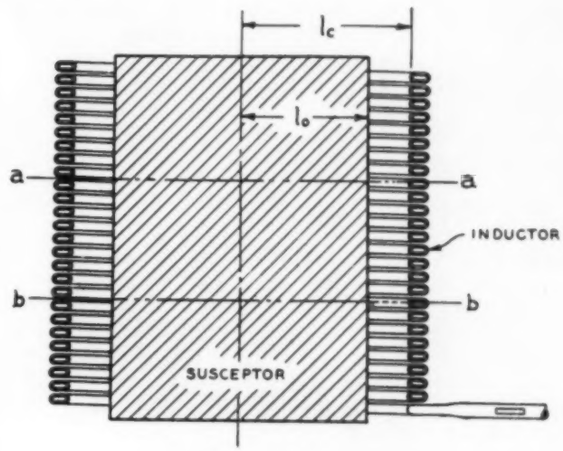


FIG. 1A

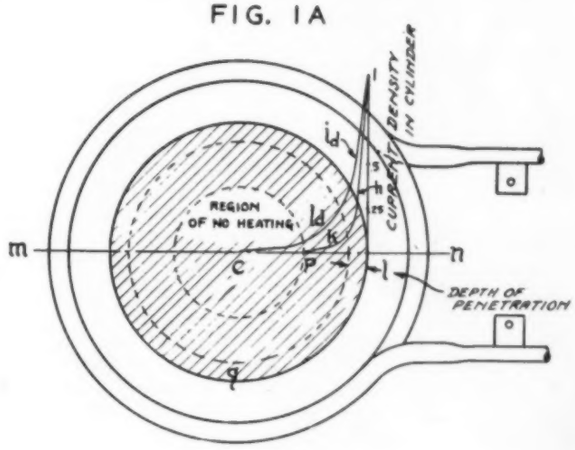


FIG. 1B

If the current in the inductor is alternating and there is no conducting matter within it, the field is still uniform even when the frequency of the current is moderately high.

We shall now consider the more important phenomena manifested when a susceptor, in the form of a solid non-magnetic metal cylinder, is placed inside the inductor.

It is well known that when a portion of space is traversed by a uniform magnetic field, there is a storage of energy in this region. If there are H lines of magnetic force per square cm., the numerical expression for this energy per cubic cm. is

$$E_1 = 0.04\ H^2 \text{ ergs}$$

When no conducting material is in the inductor and the current is alternating, the electromagnetic energy is zero when the current is zero and reaches

THE PROTECTIVE TARIFF WAS NEVER NEEDED MORE THAN IT IS NOW

its maximum value when the current is a maximum. In other words, the flux through the inductor is in phase with the current which produces it. If the frequency of the current is N, the electromagnetic energy reaches its maximum at each half cycle or 2N times per second.

Electromagnetic energy, as such, cannot be usefully employed to move matter or add to it heat. We must devise means, therefore, to convert this energy into motion if we desire to do mechanical work, or into heat if we wish to elevate the temperature of matter. We are concerned here only with raising temperature by direct transformation of electromagnetic energy into calories.

One may consider this process from either of two viewpoints and reach substantially the same results when dealing with a solid cylinder as shown in Fig. 1.

By one approach, if sufficiently skilled, we might determine the value of the induced current at each point in the susceptor, its phase at each of these points, the ohmic specific resistance of each point in the susceptor (which in general differs markedly with the temperature) and by such an elaborate mathematical process find the i^2r heating at every point. When this is done, an integration may be made that will give the total heating of the volume of material considered.

Calculations of the total energy which at each half cycle of the alternating current in the inductor, enters the susceptor and there becomes wholly converted into heat, are complicated and difficult. I have given approximate and simplified formulae in several publications,* and recently I have improved the accuracy of the formulae without much loss in simplicity. It is not in order here, however, to dwell on the mathematical aspects of inductive heating which are of interest chiefly to designers of inductive equipment. The user desires to obtain a few physical concepts only and wants to know what can be done with inductive methods that may be of practical use.

Physically we may consider the matter as follows:

When electromagnetic energy flows into the interior of a conducting mass, its conversion into heat starts at the surface where it enters. The quantity of energy converted diminishes by an equal percentage of its still unconverted value at every point distant below the surface. At a certain depth below the surface, this absorption or conversion of the total electromagnetic energy supplied is substantially complete. The gradual absorption of sunlight falling vertically on clear water of great depth is an exact analogue.

In the case of a solid metal cylinder of sufficient diameter, no traceable electromagnetic energy when supplied by current which is alternating, ever reaches its axis. The higher is the frequency of the current, the less need be the diameter of the cylinder for this to be true. The density of the current (amperes per sq. cm.) which flows circumferentially in the solid cylinder has its greatest value at the surface of the cylinder and diminishes by a logarithmic law as the axis of the cylinder is approached. This is shown by the curve i_d, Fig. 1-B.

The heating effect of this current at any given point in the cylinder is proportional, as in all other cases, to the square of the current density at the point. Hence, the rate of heating done by the current in the cylinder decays more rapidly than the current density as the axis is approached. This is shown by the curve h, Fig. 1-B. The ordinates of this curve are proportional to i^2_d.

The heating effect of the induced current is practically nil where the curve h has approached the line m-n as at p. Here it is within a few percent of its maximum ordinate which is at the surface, s, of the cylinder. Taking c as center and describing a circle through point p, we have a region within this circle in which there is practically no magnetic field and no heating due to current flowing. The metal in this region may be removed without in the least affecting the rate of heating of the metal which remains.

Steinmetz has supplied the necessary formula* to calculate very simply the minimum diameter which the cylinder should have in order that there shall be no appreciable heating by the current at the axis.

When the diameter of the cylinder is in accord with the above condition, it becomes rather simple to approximately calculate the power which the cylinder will absorb when the number of ampere turns in the inductor is known and the frequency of the current is N cycles per second. It is to be noted that of the total number of lines of magnetic force through the inductor, only a certain portion of these will enter the susceptor. Obviously, if the horizontal sectional area of the susceptor or cylinder is called s and the horizontal sectional area of the inductor (its inside diameter only being taken) is S, then $\frac{s}{S}$ lines only will cut into the cylinder when placed within the inductor. In making this statement, we consider a region within the inductor where, when empty, the field of force is uniform over the area S. Such is the case between the horizontal planes, Fig. 1-A, near the center of the vertical axis of the inductor.

We may call the ratio $\frac{s}{S}$ the "physical coupling" between the inductor and the susceptor. We will call this physical coupling C. It diminishes near the ends of the inductor and this fact must be taken into consideration by the designer when precise calculations are demanded for power absorption of the entire cylinder.

In addition to the power absorbed by the susceptor, power is required to supply heat developed in the inductor coil due to its ohmic resistance for alternating current. For unit axial length of the inductor the power absorbed, and thus wasted, is i^2r_1. To obtain useful heating, w_1, we must supply power per unit axial length of the inductor,

$$P_1 = w_1 + i^2r_1.$$

Thus the efficiency with which the susceptor is heated is,

$$F = \frac{w_1}{w_1 + i^2r_1} = \frac{1}{1 + \frac{i^2r_1}{w_1}}$$

*See "General Electric Review"—issue of November, 1922.

*"Transient Electric Phenomena"—Chapters VI and VII.

This relation may be expressed in a form to show that the efficiency of the inductive combination, as a heating device, increases when the frequency increases but decreases when the resistance of the inductor increases.

If it were not for the fact that the ohmic resistance of the inductor, due to "skin effect", increases with increase in frequency, the efficiency of the inductive heater could be made as high as we might choose by selecting a sufficiently high frequency. Practical experience and theoretical considerations confine the selection of the frequency, for optimum results, technically and economically, within fairly narrow limits. The most used frequency for non-magnetic materials is 1,000 cycles per second. For cylinders and rods of small diameter 4,800 cycles have been supplied by a motor driven generator of the inductor type. With static frequency converters, 20,000 cycles and more may be used under certain favorable conditions with economic advantage.

It is important to note that one kind of non-magnetic metal or alloy (with correct proportioning of frequency and diameter of susceptor) heats as effectively and efficiently as any other. The method is, therefore, of wide application and has merit for heating non-magnetic cylinders which are electrically conducting.

If there is substituted for the solid cylinder, a thin-wall tube of the same outside dimensions as the cylinder, it is possible in this case to devise a formula which will quite accurately express all relations which it is desired to know. The mathematics required to calculate the heating of tubes are, however, far too intricate to consider here.

"Depth of Penetration".

The quantity called "depth of penetration" has been defined and fully explained by Steinmetz. As the quantity expressed by this term is much used in making calculations and is often referred to in the literature, it is important for us to clearly understand just what it means.

Refer to the curve i_d, Fig. 1-B. Between the axis, c, and the circumference of the cylinder, the total amperes flowing circumferentially in a unit axial length of the cylinder will have a value which may be expressed by the relation $i_t = l\, i_s$, in which i_s is the density of the current at the very surface of the cylinder. Then l is a quantity by which this current density at the surface must be multiplied to give the total current. It is called the "depth of peneration" and is measured in centimeters. The formula which Steinmetz gives for calculating l is, in the case of non-magnetic materials,

$$l = 5030 \sqrt{\frac{\rho}{N}} \text{ (in cms.)}$$

in which ρ is the specific resistance of the metal (at a particular temperature) and N is the frequency, in cycles per second, of the inducing current, assumed to be of sine wave form.

If the total current in the cylinder were confined to an annulus, q, (Fig. 1-B) at the surface of the cylinder of thickness, l, and the current in this annulus is of uniform density, i_s, then the heating effect of the current would be the same as it is in the actual case.

Since the "depth of penetration,,' l, is a mathematical and not a physical quantity, it is not so useful in forming a clear picture of what actually goes on in the cylinder as the curves i_d and i_h which can be plotted with the aid of other equations which Steinmetz has given.*

The quantity l however, is very useful in the many kinds of calculations which are made in connection with inductive heating.

Susceptors of Special Shapes and Some Devices Used In Heating them Inductively.

Non-ferrous, non-magnetic metals and alloys which require to be heated for annealing or other purposes, may be classified in respect to shape as:

1. Solid round billets.
2. Solid square or rectangular billets.
3. Rods, round or square, in diameter one inch or under.
4. Drawn wire of all sizes up to about one-quarter inch or under.
5. Sheet metal in strip which is to be heated by continuous travel through the heating device.
6. Sheet metal, usually of large area, which must be heated in batches by a discontinuous process.
7. Round tubes of all sizes and lengths and wall thicknesses and tubes of square, rectangular, oval or other cross-section.
8. Masses of metal of various sizes and irregular shapes.

It is obvious that, if inductive processes of heating are to be used, the methods and devices required will vary in many respects. Yet all of the various sizes and shapes of metal listed above may be heated advantageously by making use, one way or another, of the principle of inductive heating.

Inductive methods of heating which may be employed commercially fall broadly into three general classes:

a. Those methods in which the heating is wholly by direct induction, by which we mean that the alternating current in an inductor develops an alternating magnetic field which acts directly on the susceptor, heating it and nothing else.
b. Those methods in which the materials to be heated are placed in a muffle, the muffle walls only being heated by induction.
c. Combination methods in which part of the heating of the susceptor is by direct induction and the remainder by heat radiated to it from the walls of a specially contrived inductively heated muffle.

If proper use be made of any or all of the three general methods listed, I hope to show convincingly that all non-ferrous non-magnetic and many magnetic ferrous metals having any of the forms listed above may be heated using induction, to a temperature as high as commercial requirements impose and, indeed, with better control of temperature, more uniformity in temperature and with higher economy than can be obtained by the methods now in extensive use in which fuel or electricity is employed.

That inductive methods, so meritorious, for producing heat in metals of most any shape, have come, thus far, little into use in industry, is due, I believe, largely to present business conditions—in part to

*Eq. (32) Chap. VII, "Transient Electric Phenomena and Oscillations."

lack of knowledge and appreciation of what is technically possible with inductive methods and to the small consideration engineers have given to the conveniences and economies which they might effect by using induction.

I cannot point, therefore, to many existing industrial installations where now metals are heated, but not melted, inductively, and I am forced, therefore, to pose rather as a prophet than as a historian.

Method A. Cases Suitable for Treatment by Direct Induction.

When use of the direct inductive method is contemplated, the availability of reasonably priced frequency changing equipment first deserves attention. The tonnage to be handled in the heating of billets and tubes must be sufficient to justify the installation of a motor driven generator to supply current at a frequency of not less than 500 to 1000 cycles per second and in special cases as high as 5000 cycles. Current of normal frequency, 25 to 60 cycles, is not generally applicable where direct induction methods are used, and the temperatures required exceed the temperature at which magnetism is lost.

The second consideration is technical, in that the resistivity and the least dimension of a transverse section of a solid susceptor, as a billet, be such that the greater portion of the electromagnetic energy which flows into it becomes changed into heat.

Finally the susceptor must have a geometrical symmetry which will allow it to be placed easily within an inductor coil and in a manner to permit of a close and uniform physical coupling at all points along the greatest length of the susceptor. Billets of round or rectangular section, pipes or large diameter tubing meet these conditions while the crankshaft of an automobile engine does not.

Coupling.

The importance of close coupling may be shown by reference to the curve Fig. 2. Here the curve shows the increase in overall efficiency of the heater as the coupling is varied from 0 to 1. A coupling 0 means that the diameter of the inductor is infinitely greater than the diameter of the susceptor. A coupling 1.0 means that the inductor is wound tight on the susceptor. The curve has been drawn from both experimental data and from calculations.

The calculations and results show the high importance from the standpoint of obtaining good efficiency for maintaining a close coupling.

In addition to this reason for making the coupling close is the economic advantage of getting the highest possible power factor as measured at the inductor terminals. The higher the power factor the less becomes the cost of correcting it with static condensers to give unity power factor at the generator terminals.

Speed of Heating.

No other known method can compare with the direct induction method for rapidly heating any considerable mass of conducting matter. The fundamental reason for this is that any heat which enters a mass placed in a hot chamber must enter that mass chiefly in the form of radiant heat through its surface.

Radiant heat is a form of electromagnetic energy no different, except as to wave length, from that which leaves an inductor coil which is carrying alternating current.

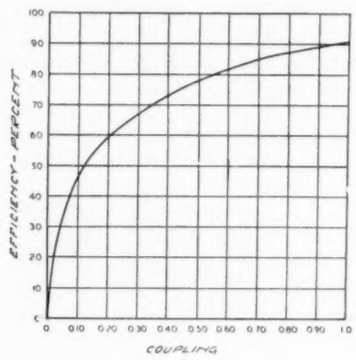


FIG 2

The radiant heat energy is a radiation produced by a frequency of the order of 6×10^{13} cycles per second. Hence when this radiant heat energy falls upon the surface of a metal from which it is but little reflected, it is all converted into heat energy in the time it has penetrated below the surface only by 5×10^{-5} millimeters or less. The heat so produced can go further into the mass by the process of heat conduction only, which is exceedingly slow in masses of moderately low thermal conductivity. On the contrary, when direct induction methods are used and a moderate frequency of, say 1000 cycles per second is employed, the conversion of the electromagnetic energy into heat in this case takes place, in large part, well below the surface, a centimeter or two, and, by proper choice of frequency, as far below as may be desired.

What limit then must we set in the speed of heating of any conducting mass? The answer is: with a sufficiently large source of high frequency power available, and with a correctly designed and water-cooled inductor, the speed of heating, even a large mass, is in principle without limit.

In a particular case tried by me, a one inch diameter steel rod four inches long was made to absorb sixty kilowatts and it came from room temperature to a forging temperature in two or three seconds. With still more power at one's disposal, this rod might have been heated as if struck by a hammer of electrical energy.

This feature of inductive heating may find in the future numerous useful applications.

Method B. Inductively Heated Muffles: Continuous Process Heating and Batch Heating.

The most simple and often most useful form of an inductively heated muffle is one in which a short or a long tubular muffle furnace is maintained at a desired temperature by heating the tube inductively with an inductor coil which surrounds it. The tube may have any desired length and be of any cross-section as round, oval, square, rectangular or semi-circular with a flat bottom. The materials of the

tube may be nickel-chrome, chrome-steel, or even graphite when provision is made to protect this from oxidation.

Whatever the material or form of the tube, it should be considered the susceptor on which the inductor acts.

The inductor winding is usually made to conform to the contour of the cross-sectional area of the susceptor. It is good practice to make the coupling between inductor and susceptor between 50 and 60 per cent. The space between the two is filled with any suitable highly heat insulating refractory.

The material to be heated as strip metal, rods or tubes, may be intermittantly placed in the muffle until it has reached the desired temperature or the same may be fed steadily through the muffle. All heating of the material results from heat radiated to it from the inside wall of the muffle. It is easy to maintain the heating chamber filled with a protecting gas.

The wall thickness of a tubular muffle would be chosen usually from ⅛ to ¼ inch, but it may be much thicker, if desired, without appreciably altering the efficiency of the muffle-heater.

A muffle heater of this character, with heavy duty to perform should be generally not less than about two inches in its least outside diameter. The

FIG. 3

reason for this is that a higher frequency is required to inductively heat a susceptor efficiently which has a small diameter than one of larger diameter. The highest frequency which may be economically supplied with a generator is about 5000 cycles and an inductor type of machine is required for this.

It takes about 5000 cycles to efficiently heat a susceptor as small as two inches in diameter. Wire wound alternators are now standardized to give 960 or 1000 cycles. This frequency is quite adequate to heat a four inch diameter susceptor but hardly high enough for one only two inches in diameter.

The efficiency, uniformity of temperature, and the ease of control of temperature of an inductively heated muffle is surprisingly satisfactory.

A manufacturer of razor blades has in service six inductively heated muffle furnaces which are giving entire satisfaction both from the technical and economic viewpoints. Three of these muffle heaters were photographed before shipment and are shown in Fig. 3. One of the heaters appears with one end fitting taken off to reveal the sectional construction of the muffle, and the other heaters are shown partially and entirely complete.

Following is a brief description of the power-generating equipment, the six muffle heaters, and their performance; also of the economies they have effected.

Power Generating Equipment

The frequency changer set consists of a General Electric Company 60 kw., 3 phase, 550 volt, 4800 cycle generator, together with control panels, instruments, voltage regulator and exciter. The generator is directly connected to a standard 125 h.p., 3 phase, 440 volt, 3600 rpm. squirrel cage induction motor.

Muffle Heaters

The overall dimensions of the muffle heaters are 10″ x 10″ x 14½ ft. long. The muffle is made of a welded nichrome tube 2″ in diameter and flattened to an oval shape. Its wall thickness is 0.1″ and it is also 14½ ft. long.

The entire length of the muffle is covered with heat insulation and inserted in the inductor. At the exit end of the heater the muffle is held in a fixed position while the other end is free. At the free end provisions have been made to allow for the expansion of the muffle which has been found to be 1¾″.

The inductor consists of a thin wall copper tubing wound the full length of the muffle and is water cooled. Taps are provided in order to control the power input to each heater.

Performance

The heaters operate at a temperature of 812°C. (1500°F.) and it is essential that a uniform temperature be maintained throughout the length of the muffle with the exception of one foot from the exit end. The number of turns per inch are increased at this point to bring the temperature up to 870°C. (1600°F.)

The heaters are electrically connected so that a balanced 3 phase load is had when all the furnaces are on. In order to provide a balanced load when one or more furnaces call for a drop in temperature (power off) a dummy load is used. This load consists of a water-cooled resistor and draws about the same amount of power as one heater. There is one dummy load for each heater.

A temperature controller is connected to each heater and these are so arranged as to provide three controls, namely (1) off (no power), (2) holding power (constant temperature) and (3) raising power (rise in temperature). These controls operate contactors mounted on the switchboard in the generator room and function according to the temperature demands of the muffle.

If a temperature drop is required in the muffle, the "off" contactor closes and the generator is connected to the dummy load.

When the temperature is just right, the "holding" contactor closes and the maximum number of turns is connected across the generator.

If the controller calls for a higher temperature, the "raising" contactor comes in and the generator is then connected across the minimum number of turns.

As stated before, the inductor has several taps connected at intervals. With these taps, the "hold-

ing" and "raising" power may be adjusted within wide limits. It was found by test that the following power adjustments were best for one size of strip steel:

"Holding" power—6.8 kw.
"Raising" power—8.8 kw.
Off (dummy load)—7.5 kw.

With the power taps adjusted as above, it requires but 40 minutes to bring muffle up to temperature from the cold.

The thickness of heat insulation on the muffle was so designed as to give a reasonable efficiency and at the same time permit the temperature of the muffle to drop quickly. This feature is highly desirable as it gives a precision control of the temperature. For example, after the working temperature has been reached, it is possible to raise the temperature 25°F. in one minute with the "raising" contactor and also cause a drop of 40°F. per minute on the "off" position. In the general operation of these muffle heaters, a temperature is held throughout the day at 1600°F. with a variation of less than 0.4%.

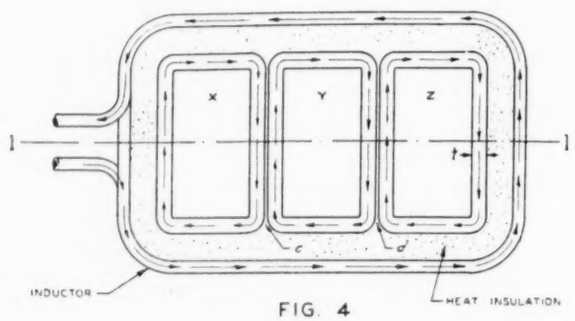


FIG. 4

Economies

The six heaters operate continuously with a power input of 62 kw. measured at the motor terminals.

The total production of heat-treated strip steel for the six heaters amounts to 92 lbs. per hour giving a power cost of 5 mils per pound at 7.5 mils per kw-h. or $5.00 per 1000 lbs.

The cost of heating 92 lbs. of steel per hour in the former gas fired furnaces was found to be at the rate of $22.00 per 1000 lbs. While this amount only represents 39% of total capacity of the gas furnaces, it is significant because the cost per 1000 lbs. of treated steel when operating at 100% capacity was $8.50. Following is a summary of the savings gained by using the high frequency heaters over that of the gas fired muffles at various capacities:

Percent of gas furnace capacity	Savings per 1000 lbs. by electric furnaces over gas
100%	$3.50 per 1000 lbs.
75%	6.00 " " "
52%	11.00 " " "
39%	*17.00 " " "
35%	19.00 " " "

*This percent of gas furnace capacity was actually checked for a four month period and represented a saving of over $3,000.00 for this period or $9,000.00 per year.

The wide variation in costs of the gas furnaces may be explained by the fact that it is necessary to keep the gas on even if the furnaces are not in production, due to the great length of time required to bring the muffles up to working temperature. This usually requires from three to four days while the electric muffles require only 40 minutes to attain the proper temperature.

Attention is called to the fact that the above considers the relations of the fuel costs only.

Inductively Heated Muffles for Batch Heating.

In the design of muffles for batch heating of a large volume of material at a time, use may be made of a most valuable method of induction. We designate this, **Multiple Chamber Method.**

To better understand it, refer to Fig. 4. Here the susceptor is shown as made up of three hollow rectangular castings of say, chrome steel. The number of such castings, however, may be more than three if desired.

In practice, the wall thickness, t, of these castings would be from one to two inches but may be greater. In the direction vertical to the plane of the paper, each casting may be as long as is required to form a chamber of the desired length. A casting, however, constituting a heating chamber would not be a one-piece casting but would consist of many pieces fitted together, each piece being about four inches thick in the direction vertical to its plane.

This feature of the construction may be clearly understood by referring to the side view, Fig. 5, of a section on line *l-l* of Fig. 4.

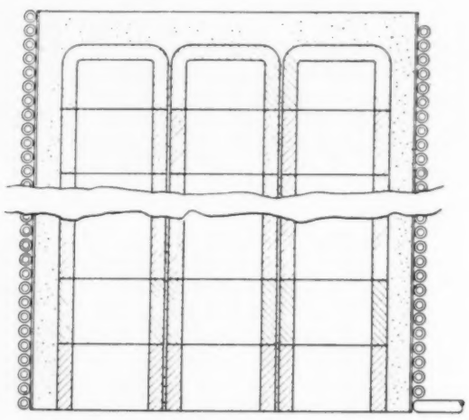


FIG 5

The three chambers x, y, z, are placed very close to one another, a small fraction of an inch only being allowed for electrical insulation between the sets of castings. If each pair of castings join at one **point** only, as at point c or d, Fig. 4, no cross currents will flow and the performance of the inductive heater will not be affected in any way. The multiple chambers thus made and placed, are surrounded with a single inductor which consists of a suitable number of turns of round or flattened copper tubing. This inductor carries both water for cooling and alternating current of a suitable frequency to induce currents to the best advantage in the susceptor.

The manner in which currents circulate in the susceptor is interesting. Referring to Fig. 4, let it be assumed that at a given instant the direction of the current in the inductor is that shown by the arrows. Then the periphery of the group of chambers has an e.m.f. developed in it equal at every point of the periphery, but no e.m.f. acts along the vertical sides of the chambers where these are adjacent.

It results that large currents flow in the walls of the several chambers which are sensibly equal in each chamber and at all parts of any one chamber. The directions of flow of these currents are indicated by the arrows placed around the chamber walls. The **adjacent** walls of the chambers possess little inductance, and dividing the susceptor into two or several sections is equivalent electrically to merely increasing the total ohmic resistance which the currents in the susceptor must overcome.

It results finally that each chamber will reach under the influence of induction produced by a single inductor exactly the same temperature and that this temperature is extremely uniform throughout the space enclosed by the multiple chamber-walls.

The following advantages of this type of heater may be claimed:

1. The inductively heated resistor (the susceptor) may be constructed of an inexpensive alloy.

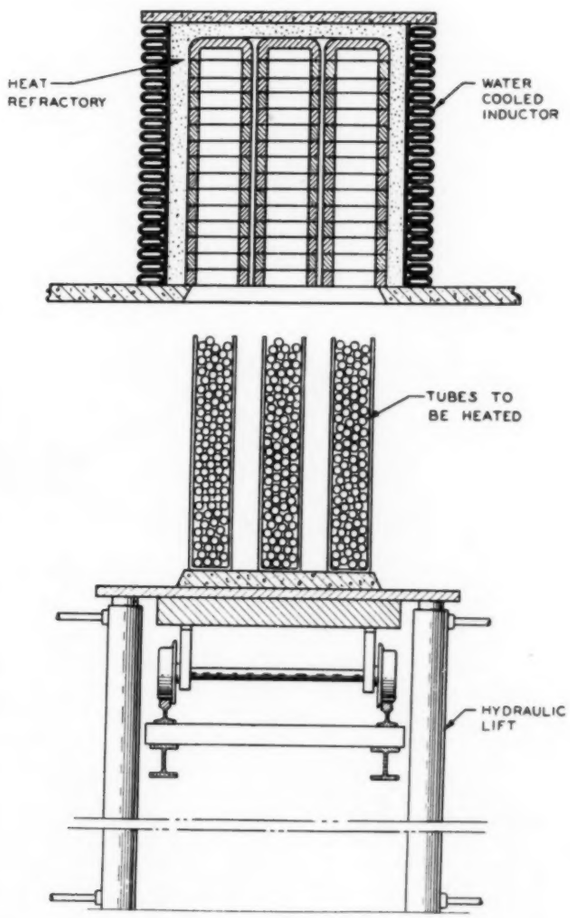


FIG. 6

2. The susceptor is an assembly of multiple castings which are alike and simple.
3. If by overheating or from any other cause, one or even several of the unit castings which constitute a chamber should open circuit and fail, the heater as a whole will continue to function until the batch of material being treated is finished. A repair may then be effected easily by replacing the defective unit casting with a spare.
4. The mass of the resistor is such that it has a large heat capacity and hence an accidental short time rise in the rate of heating will not overburden or destroy it. Likewise, if the power input fails for a short period, the heat stored in the resistor itself is sufficient to maintain the temperature of the chambers for an appreciable time.
5. Since the susceptor is heated inductively, its temperature will make an instantaneous response to any increase or decrease of voltage at the inductor terminals. From this it follows that by automatic devices, control of the temperature of the walls of the multiple chambers is exact and simple.
6. By subdivision of a given mass of material to be heated, so that equal masses occupy each of the multiple chambers, the heat given to each mass by radiation reaches the interior parts of the mass very much sooner than it would if the entire mass to be heated were in a single bulk and placed in a single chamber muffle.
7. Since the space between the inductor and susceptor may be filled with the highest possible heat insulator, as sil-O-cel bricks, the loss of heat to the exterior is slow and the heat developed will find its way in very large measure into the material being heated.
8. Chrome steel castings may be safely held at a high temperature, say 1300°C., hence the upper working temperature of the muffle is high.

In Fig. 6 is shown a suggested three chamber inductive muffle specially arranged for the rapid and uniform heating in batches of non-ferrous tubes.

The limits of this paper will not permit a discussion of further features of this method of heating.

The question of the optimum frequency of current to energize the inductor depends on so many circumstances and conditions that it will not be discussed here, more than to say that normal frequency current may probably be used for inductive muffles of large dimensions. In any situation where 1000 cycle power is available, an inductively heated muffle of any size could certainly be heated to the very best advantage and the power factor at inductor terminals could be raised to unity with relatively few capacitors.

Single Sheet Metal and Continuous Strip-Metal Heating.

Metal in the form of a single sheet or a strip of sheet metal, especially if thin, is particularly difficult to heat by any known process of direct induction. Even if the technical difficulties become surmounted, the cost of heating sheet metal by this process would be prohibitive. The reason for this latter statement becomes apparent from the following considerations: The object, of course, in putting

heat into a sheet is to raise its temperature. Now, only those calories added to a sheet which are retained in the sheet during the interval of heating are effective in raising its temperature. Sheet metal has an extremely large ratio of surface to volume. As soon as the metal sheet acquires much temperature, the heat radiated from its large surface becomes very great. This radiated heat, not at all effective in raising the temperature of the sheet, is lost into space and must be supplied from the source of power. Thus to heat sheet metal with any degree of economy, it is necessary to devise means whereby the heat put into the sheet by induction or otherwise is conserved and not lost in large part into space.

Many patented processes have been proposed for heating sheet metal solely by direct induction but all of these are ineffectual from an economic standpoint for the reason stated above.

We may state the fundamental nature of the problem and the requirements which must be met for technical and economic success as follows:

a. The thinness of sheet metal requires that induced currents shall flow in plane of sheet to heat it effectively by direct induction.
b. To obtain economy in the heating of sheet metal, the heat given to the sheet must be retained, in large part, within the metal and not radiated into space.
c. Uniformity in the rate of heating of all parts of a sheet is essential to prevent warping of the metal and to bring it to a final temperature that is the same over its entire surface.
d. In the majority of cases, the sheet metal must be protected from oxidation while being treated. The treatment must be carried on in an inert atmosphere.

Fulfillment of the above requirements for heating single sheets of metal or a long sheet which moves continuously through the heater is best accomplished electrically as follows:

a. by resorting to an inductively heated muffle of very special design in which the sheet is heated entirely by radiation from the walls of the muffle (radiation inductive sheet heater) or
b. by employing a similar type of inductively heated muffle so modified that the sheet metal becomes heated both by radiation from the muffle walls and by induced currents made to flow in the plane of the sheet (semi-inductive sheet heater).

Principles of the "Radiation Inductive Sheet Heater."

The electrical principle involved in this type of heater is very similar to that employed in inductively heated muffles for batch heating as described on page previously and following in connection with Fig. 4, page 72.

Figs. 7-A, 7-B and 7-C, which are different views of the same device, have been prepared in a manner to make this type of heater quite clear without adding much written description.

The following comments are pertinent:

1. A strip of sheet metal which is passed through the slot, s, Fig. 7-A, or G 7-B, may be narrow or as wide and as thick as will permit it to pass easily through the slot.

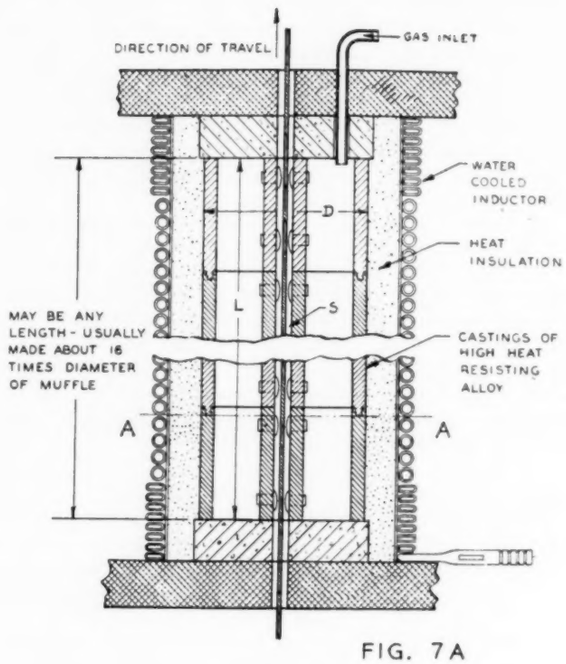
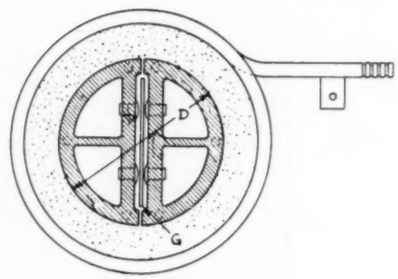


FIG. 7A



SECTION A-A

FIG. 7B

2. The length, L, which is the active part of the heater, Fig. 7-A, may be made as long as may be required. In general, it would be about sixteen times as long as the diameter, D, Fig. 7-A and 7-B. The greater the length, L, the greater is the length of sheet metal which can be heated in a given time to the desired final temperature.
3. The castings which constitute the susceptor may be made from chrome-steel and it is thought that this form of resistor may be operated continuously at around 1300°C.
4. The final temperature of the sheet metal as it emerges from the heater cannot exceed the temperature at which the susceptor is held but may be made as much less as wanted by adjusting the speed of movement of the sheet through the heater.
5. The operating temperature of the faces of the resistors between which the sheet metal moves, may and should be maintained very constant by an automatic controller of the "Leeds & Northrup" type. This controller would function in response to an e.m.f. generated by a thermocouple embedded in the castings and

would control the temperature by varying the voltage at the terminals of the inductor.

6. A radiation pyrometer could be sighted on the emerging sheet and by automatic means control the speed of travel of the sheet through

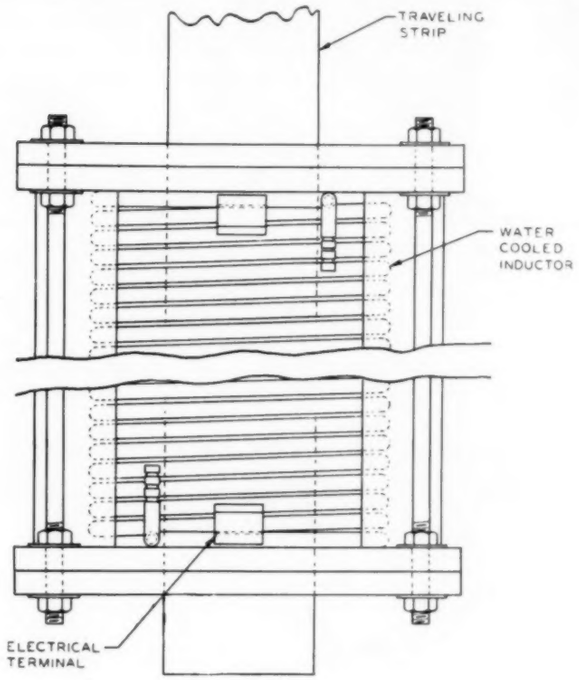


FIG. 7 C

the heater. In this way or in some similar manner, the sheet could be made to emerge at the desired fixed temperature.

7. Carefully made tests show that the sheet metal, when passed through the heater, is heated with perfect uniformity in the direction of its width and hence no warping of the sheet occurs.
8. Theory and tests show that the coupling between inductor and susceptor (the resistor castings) should be about 0.6 for highest economy in heating.
9. The space between inductor and susceptor should be filled with a refractory of the highest possible heat insulating property. When this is done, the rate of loss of heat through the refractory is almost negligible. It is to be noted that the surface for loss of heat radially is $\frac{\pi}{2}$ or about 57 per cent greater than the two surfaces of the sheet metal and that the heat flow from the outer surface of the susceptor must take place through a considerable thickness of the best of heat insulation. Thus no other type of sheet heater, which exposes any portion of the hot sheet metal to radiation into the open, can so perfectly conserve all the heat which the sheet receives.
10. By making the heater considerably longer than its diameter, heat losses along the direction of its length are reduced to be negligible.
11. The speed with which the sheet may be made to travel and hence the total weight of metal that can be treated per hour may be increased in proportion to the length, L, given the susceptor. (Fig. 7-A). No electrical limit is set upon this length.
12. This type of heater may be readily kept filled with an inert atmosphere which protects from oxidation both the resistors and the material treated.

A heater of the kind described above was constructed of a size to heat either unit lengths or a continuous strip of sheet metal 5" wide and of any thickness up to ¼ inch.

Laboratory tests were made which confirmed all our expectations of merit, and empirical data were obtained which will prove very useful to the designer. No "radiation inductive sheet heater" at the time of this writing has been placed in commercial use.

The writer believes, however, that it is bound to be appreciated if given a fair trial in commercial production. The heater is equally adaptable to the heating of non-ferrous and ferrous sheet metal of wide variation in width, length and thickness. It will serve to heat, one at a time, sheets of short length. Such short length sheets, shorter than the susceptor, would be quickly inserted in the slot and kept there the proper time to acquire the desired temperature and then dropped out into a quenching medium or fed into a machine.

Principles of the "Semi-Inductive Sheet Heater."

The "radiation inductive sheet heater" just described induces only small currents in the sheet metal and these add but little to the heat received by the sheet from radiation. This will be understood if one refers to Fig. 7-B and notes that equal currents flow in opposite directions in the opposed faces of the resistors between which a sheet is passed. The tendency, therefore, of such current as is induced in the sheet is to flow directly across the opposite side in the reverse direction. In the case of a sheet that is thin, the oppositely directed e.m.f.'s on the two sides of the sheet nearly neutralize. If the sheet has a thickness comparable to the depth of penetration, sufficient current may flow in a sheet of such thickness as to add an appreciable amount of heat by so-called direct induction. However, if it is desired to have heavy currents directly induced in a sheet, matters must be so arranged that lines of induction are developed which cut the sheet at right angles to its plane. If this is done, currents will tend to flow in the sheet in its own plane. Such currents may be made large and add much heat to the sheet.

With these thoughts in mind, the writer had the flat faces of the resistors slotted in the manner shown in the three views of Fig. 8.

A study of these views will reveal that lines of induction are developed which pass through the loops made by the tortuous path of the currents flowing in the faces of the resistors. These cut the sheet at numerous places in a direction which is, in general, vertical to its plane. These lines of induction produce numerous swirls of current in the plane of the sheet which thus becomes in part heated by direct induction.

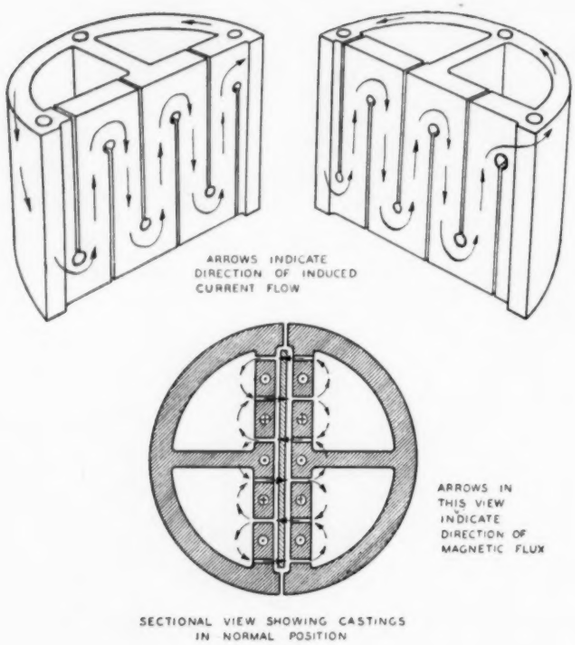

ARROWS INDICATE DIRECTION OF INDUCED CURRENT FLOW
ARROWS IN THIS VIEW INDICATE DIRECTION OF MAGNETIC FLUX
SECTIONAL VIEW SHOWING CASTINGS IN NORMAL POSITION

FIG. 8

The advantage of this modification whereby a sheet is heated partly by direct induction may not be great for increasing the rate of heating of the sheet. It is thought, however, by several experimenters that when chromium plated steel is heated to cause some of the chromium which is in contact with the steel to migrate into the steel, it is necessary to develop the heat in the steel inductively and not by radiation from without.

The process of making a coherent non-porous chromium plate on steel by high frequency induction is much in favor and is commercially applied. The application, however, has been confined to rods, tubes, large diameter hollow cylinders, etc. No attempts made by experimenters to apply this direct induction process to sheets have been successful, chiefly on account of the seeming impossibility of heating sheets by direct induction uniformly to avoid warping. The "semi-inductive sheet heater" described above may permit the accomplishments desired. At least, the plan proposed above, appears to the writer sufficiently promising to justify the expense of giving it a full trial.

II. Heating Magnetic Steels Inductively.

Any consideration of a mathematical treatment of principles which apply in the inductive heating of magnetic steels is quite beyond the scope of this paper. I shall call, however, to your attention a few physical phenomena which it is well for the designer and user alike to keep in mind when the inductive heating of magnetic steels is under consideration. The main agent in heating magnetic steels is the circulating current induced in the material.

Much has been said about heating due to hysteresis loss. This is a factor but a very unimportant one. The magnitude of the circulating current is related in a very complicated manner to the magnetic flux density in the steel and to its rate of change. Thus, if a one-half inch diameter rod made of non-magnetic nickel-chrome steel is placed in a solenoidal coil carrying current of 2000 cycles and having the ordinary number of ampere turns per foot usually employed, around 20,000, this rod will heat very little, never reaching a visible red. If now, a rod of the same dimensions but made of ordinary magnetic steel is substituted for the non-magnetic rod, it will be found that it heats in about 20 seconds to the uniform temperature of about 600°C. and then refuses to get any hotter. The simple and correct explanation of this important observation is that the magnetic material carries, while magnetic, many times the flux that the non-magnetic material carries. At somewhat over 600°C., the rod of magnetic steel is equally non-magnetic with the nickel-chrome steel.

If a billet of magnetic steel three or more inches in diameter is placed in a solenoidal coil and 20,000 ampere turns per foot are employed, it will be found that it heats very effectively and rapidly up to the temperature where magnetism is lost even when the frequency of the inducing current is only 60 cycles. A billet three inches in diameter can be heated beyond this point using 60 cycle current but only by greatly and impractically increasing the amperes in the inductor.

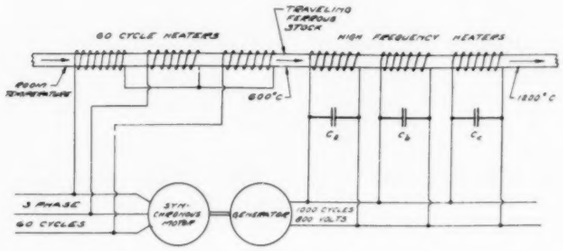


FIG. 9

If when this three inch billet has reached 600°C., the 60 cycle current in the inductor is changed to a current of equal amperage but having a frequency of 1000 cycles, the billet will continue to rise rapidly and may be melted.

Now it can be shown that the kilowatt minutes per pound of magnetic steel necessary to bring the temperature to 600°C. is just about equal to the additional kilowatt minutes required to bring it to a forging temperature of 1200°C.

The obvious commercial deduction from what has been said is that in many cases where three inch diameter or larger billets are to be heated to a forging temperature, the first half temperature stage of the heating may and generally should be done with normal frequency current and the second stage with high frequency current, generally 1000 cycles.

Fig. 9 is a diagrammatic layout for heating billets using normal frequency of 60 cycles for the first stage and 1000 cycle current, obtained from a generator, for the second stage.

To maintain unity power factor on the 60 cycle line, the high frequency generator is driven with a three phase synchronous motor. This is oversize in k-v-a. and the field so excited that the leading cur-

rent which the motor takes equals the lagging current taken by the 60 cycle inductor coils.

The power factor of the high frequency line is corrected in the usual manner with static condensers. The number of capacitor units required, when the frequency is 960 cycles, is but one-sixteenth that which would be required if the frequency were 60 cycles. This makes the investment cost small for power factor correction. This method of heating billets has been elaborately tested and found good in all respects. It has not been placed in commercial use but in my judgement, it has large commercial possibilities.

It may be remarked that the above method is not confined to round material, but may be applied to square or to more or less rectangular sections.

APPLICATIONS OF DIRECT INDUCTION TO STRAIGHT FERROUS TUBES AND PIPES

This application of induction to the heating of straight tubes and pipes is very simple and presents

FIG. 10

no complications nor requires unusual equipment provided the tube or pipe has a diameter sufficient for effective heating with the frequency available. For heating tubes three or more inches in diameter, very effective heating can be done with current of the usual frequency used in metal-melting practice. Where motor generator sets are used for this purpose, to supply the high frequency power, a frequency of about 1000 cycles per second is now very generally recognized as being most satisfactory from both technical and economic considerations. Any problem which involves the heating without melting of symmetrically shaped metals, solid or tubular, which are over three inches along the smallest dimension of a right section, may therefore be handled with what may be termed "standard high frequency power equipment." Owners of such equipment, and there is now installed about 12,000 kw. in the United States, may have at times an excess needed for their melting requirements. It is well for these to know the uses, other than melting, to which the equipment may be put.

If the tubes are of smaller diameter, down to about one and one-half inches, a higher frequency than 1000 cycles is indicated. High frequency generators of the inductor type giving 4800 cycles are now in commercial use and the current supplied by these will heat efficiently tubes, rods, etc. of the smaller diameters.

When a steel tube is chromium-plated, the cohesion and quality of the plating is greatly improved if the tube is heated *by induction* to 1000°C. or over.

The Heppenstall Company of Pittsburgh, Pa., have been using the inductive method for heating chromium-plated tubes. The writer is greatly indebted to this company for taking and for allowing him to publish the very beautiful and instructive photograph which is reproduced in Fig. 10.

As plainly appears in the photograph, the tube being heated passes through a relatively short inductor coil and is regularly and controllably rotated and advanced at an adjustable speed by the revolving asbestos board discs on which it rests. This ingenious and effective mechanical device was initiated and constructed by The Heppenstall Company.

The inducing current is supplied at 960 cycles from their 150 kw. high frequency generator equipment which was installed by them and is chiefly used for melting high grade steels.

Long versus Short Coils for Tube Heating

Since generators are built to supply high frequency current at a given voltage, usually 800 volts, and as it may be assumed that a certain number of pounds of metal are to be heated in the unit of time, it is well to enquire what may be the relative merits, under these circumstances, of long and short inductor coils.

In Figure 11 is shown diagrammatically two coils, one long and one short.

For the absorbtion of equal power in the two cases the longer coil is to be preferred as analysis shows there will be less copper loss in it than in the short coil. Hence the efficiency of a heater with proper designing will be greater in using a long coil.

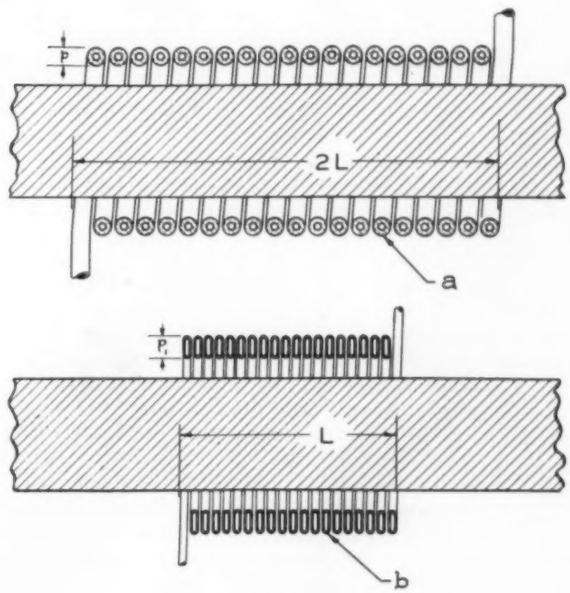


FIG 11

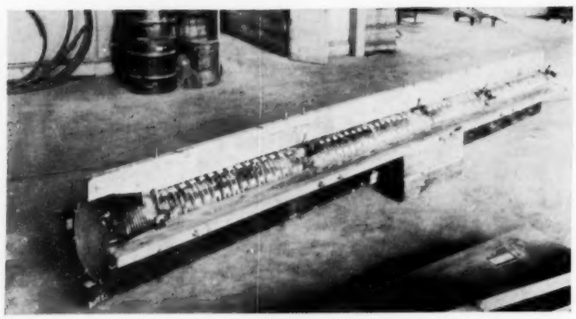


FIG. 12

Our conclusion is that from the users standpoint, it is to his interest to use as long an inductor coil as may be practical under his existing plant conditions.

Method of Inductively Heating a Pipe and Holding Same at the Upper Temperature

When for any reason a pipe is to be raised by induction to a certain upper temperature and then maintained at this temperature for a set period, this may be done by placing the pipe in an inductor coil as long as or somewhat longer than itself. To heat the pipe with economy, the inductor coil should have an inside diameter about 43% greater than the O. D. dimension of the pipe. The space between the two is then conveniently filled with silica sand. This provides excellent heat insulation. By setting inductor and pipe in a vertical position, the sand may be poured in at the top and removed from the bottom by opening a trap. The coil is then ready to receive a second pipe.

Fig. 12 is a view of the coil made for heating in the above manner, 12 foot pipes, 6 inches inside diameter. A decided merit of the inductive method of heating pipes or other large articles of a cylindrical shape is the highly uniform temperature from end to end which may be obtained. The coil for pipe heating shown in Fig. 12 has been used with much satisfaction by the U. S. Pipe & Foundry Company at Burlington, N. J. In this case, the coil was supplied with current obtained from a 300 kw. generator, and the frequency was 960 cycles. The holding power, measured at generator terminals, to maintain the pipe steadily at a temperature of 950°C., is about 65 kilowatts. Knowing the total area of the outside surface of the pipe, we obtain the rather useful figure that the power lost per square foot of pipe surface when at a temperature of 950°C. is 3 kilowatts. This is the power which escapes through 1⅜" of silica sand under a temperature gradient of 930°C.

In the case described the pipe was made of cast iron. It might have been heated effectively, however, if made of any other metal or alloy.

Roll Heating

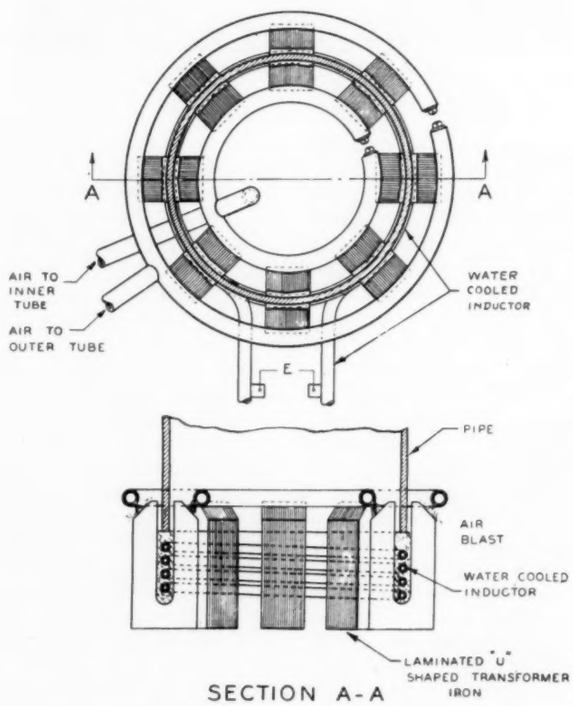
The inductive method is ideal and superior to any other conceivable method for heating steel or cast iron rolls in the process of their manufacture. As in the case of pipe heating just described the coil and roll are of about the same length. Both are set in a vertical position so the roll may be first lowered into the coil and when at the proper temperature, further lowered, for quenching into a water filled tank. In this case no heat insulation between inductor and roll is used. The speed of heating is so adjusted that the desired temperature gradient from surface to axis of roll is obtained just before quenching. The outside surface of roll may be made thus very hard and the interior tough and softer.

These statements on roll heating are based on experiments thoroughly carried out.

The heating of cannon and big guns by the same inductive operation as applied to roll heating is here suggested as seeming to be very practical and useful. It may be added that if the gun has a large bore, a full length inductor coil may be placed inside the bore. By so doing, the interior surface of the gun may be heated faster and hotter than metal nearer the outside.

Inductive Heating of Ferrous Materials Below Decalescent Point

Ferrous metals in variously fabricated forms as rods, billets, tubes, pipes, sheets, auto-claves, etc. may conveniently be placed in two general classes. In the *first class* belong all solid ferrous metals which in fabricated form require a re-heating in order that some further operation or heat treatment may be given the metal itself. Thus, oil-well pipes are reheated to be normalized; billets are heated to be forged; steel rolls to be hardened; steel sheets to be annealed; etc. In most every case under class one, the final temperature needed is well above the temperature where any magnetism is retained. Due to this fact, inductive methods generally require the use of current of a higher frequency than sixty cy-



SECTION A-A

FIG. 13

cles and the investment cost must include a frequency changer.

In the *second class* belong all ferrous metals which are heated, not for any operation to be performed on the metal itself, but for the purpose of using the heat given to the metal for heating something else. Examples are many. Thus, a pipe line may be inductively heated so the fluid it carries shall become heated. An auto-clave may be inductively heated in order to heat the chemical inside it. A striking case is the use of inductive heating of automobile bodies to dry the paint by heat.

The temperatures required are very generally well under the point where magnetism is lost.

Many cases under class two have been brought to the writer's attention in which 60 cycle and even 25 cycle current may be used to excellent advantage. This, however, is a branch of the subject of heating solids by induction which the writer must pass over with the few remarks made above.

Heating One End of Large Pipes

It is frequently required to heat for forging a large medium or small diameter pipe at one end and a certain small distance back from this end. This may be done most efficiently and conveniently in most cases by inserting the end of the pipe to be heated into a water-cooled solenoidal coil which has an inside diameter but slightly greater than the pipe. In this case the pipe will heat quickly, if the power used is sufficient, over that length only which is within the coil. The line of demarcation between the heated and unheated portion is sharp and we are thus able to avoid wasting energy by heating any portion of the pipe which it is not desired to heat.

Special cases have arisen where it is required to heat a large or medium diameter pipe to a forging temperature back for only an inch or two from its end. To meet this demand, a special type of inductive heater has been designed and used which employs transformer steel. This is shown in Fig. 13. Here is seen arranged in a circle, U shaped transformer steel punchings. When, as will generally be the case, high frequency is used, the steel laminae should be not over 7 mils thick. The energizing coil is circular and rests in the bottom of the circular channel which the assembly provides. The pipe end is inserted in the upper portion of the channel which it nearly fits. Lines of induction thread the wall of the pipe over a certain portion of the part to be heated. These lines pass radially through the pipe end and the induced current flows circumferentially round the pipe. This heating current is confined closely to the region to be heated. The arrangement provided (which may be readily understood by a close study of Fig. 13) will heat the extreme end only of a pipe and will do this with the minimum of wasted energy. It is to be observed that the circle of laminations may be readily increased or decreased in diameter to provide for receiving an end of pipes of greater or less diameter.

Heating a Central Section of a Large Pipe So It May Be Bent

This may be accomplished on a shop floor near to or far from the source of high frequency current

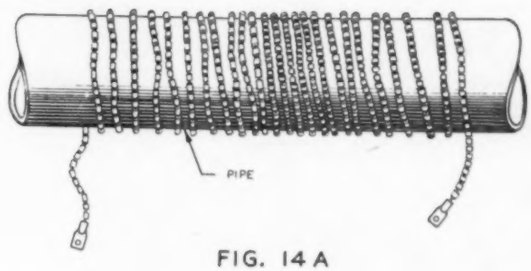


FIG. 14 A

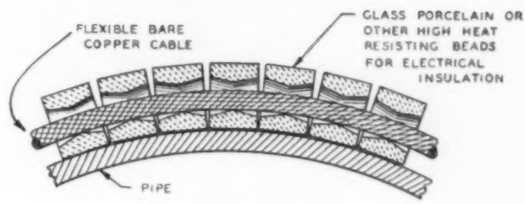


FIG. 14 B

required. Unit lengths, say 40 ft. each, of flexible copper conductor are used. To prevent corrosion by oxidation, these flexible conductors are heavily plated with nickel or perhaps chromium. On the flexible conductor, beads of refractory material are strung. To heat a certain length of pipe, say three feet, one quickly winds the insulated conductor tightly round the pipe until it is covered with a coil over the length to be heated (See Fig. 14, A and B). The coil is then fed with high frequency current and any chosen length of the pipe may be heated at any desired speed. The current through the coil may be adjusted to the desired value by selecting a suitable voltage to apply to the ends of the coil. If the high frequency generator is not at the time supplying any other load, the voltage desired may be adjusted at the generator switchboard. If the voltage of the generator must be held constant, then an auxiliary high frequency auto transformer may be used.

By the means described above, a 2 foot, or any large diameter pipe may be heated where it rests in the fraction of an hour.

Several hours would be needed to place the pipe in a fuel-fired furnace, heat it up and then remove it for bending.

Method for Leading Heat Into the Interior of Masses

Fig. 15 shows a section of pipe of any desired length cast of chrome steel or similar material. The pipe section is cast with re-entrant pieces as illustrated. The re-entrant pieces are slotted with a tool. Surrounding this pipe section, which serves as a susceptor, is the inductor and between the two is a good heat insulator.

When alternating current is flowing in the inductor, the periphery of the susceptor has induced in it an e.m.f. at its every point. Current is thus caused to flow in the path shown by the arrows. (Fig. 15) The entire susceptor will become uniformly heated if the cross-section of the current-path is everywhere the same. If, however, the cross-section of the current-path is made less in the re-entrant pieces, which act as resistors, these will heat more than the circumferential current-path in the susceptor.

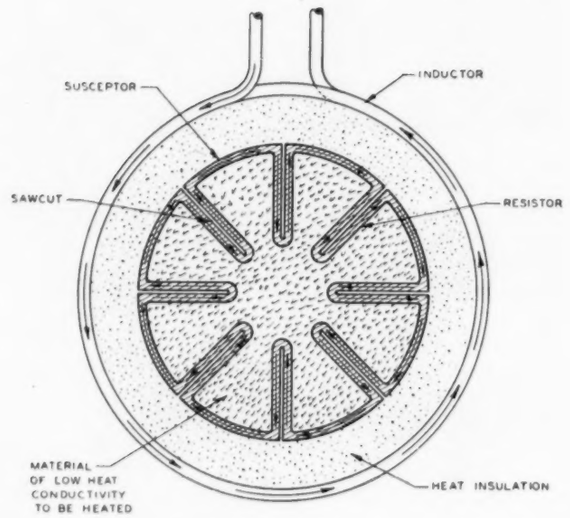


FIG. 15

It will be readily understood that if the interior of the susceptor is filled with any powdered or granular material which is a very poor conductor of heat, this material will be heated more rapidly and more uniformly than it would be if placed within a smooth wall pipe not provided with the re-entrant resistors. The material is exposed to a much greater heating surface and if desired, the re-entrant resistors may be run at a higher temperature than the circumferential portion of the susceptor.

The principle of re-entrant resistors may be applied in many different types of construction. It may be used to heat fluids or gasses which are made to flow through tubular susceptors constructed in a manner similar to that just described.

Batch Sheet Heating By Semi-Direct Induction

The principle described below and illustrated in Fig. 16 was tested for operativeness but has not yet been put in commercial use. Only a cursory outline of the principle involved can be given here. It is this: copper conducts heat about ten times as fast as steel. This fact may be utilized to heat a stack of steel sheets to 700 or 800 degrees C. as follows:

Copper sheets about ⅛" thick are selected which are three to four inches greater in dimension both ways than the steel sheets to be heated. Thus, if the steel sheets are 48" x 36", the copper sheets would be chosen ⅛" x 52" x 40". These copper sheets are heavily nickel-plated. A stack of steel and copper sheets are laid up so that for every copper sheet there will be several steel sheets, the number to depend on th thickness of the steel. In our tests about eight 1/16" steel sheets were used to one copper sheet. All sheets are so laid up that their centers conincide. The stack of horizontally placed sheets may be made three or more feet high. The copper sheets of this stack will project 2" over the edges of the steel sheets. A chamber open at the bottom and lined inside with refractory brick is provided. This chamber on the inside is two or more inches greater in its horizontal dimensions than the copper sheets. The chamber is surrounded with an inductor coil, the windings of which lie in a horizontal plane. The stacked pile of steel and copper sheets rest on a refractory bedplate which is carried on a flat topped buggy. This, with the sheets, is rolled on a truck below the reception chamber. A mechanical device elevates the pile of sheets into the chamber which then becomes tightly closed by the refractory base piece on which the sheets rest.

The inductor coil is now energized with 60 cycle current. The copper sheets which overhang the steel sheets now become the susceptor. Heavy currents flow in the periphery of the copper sheets, but not, on account of skin effect, in the edges of the steel sheets. The heat generated in the copper sheets is quickly conducted to the very center of these sheets and is given by slow conduction to the steel sheets. If the heating is not conducted too rapidly, the entire mass of copper and steel will come to the uniform temperature desired. The steel sheets may thus be annealed. The heating, of course, is carried on with the chamber filled with an inert gas.

The stack is allowed to partly or wholly cool off while in the chamber. It is then lowered from the chamber and rolled on its buggy from underneath the chamber and a new batch is put in. The copper sheets may be used over and over again many times. To prevent the copper sheets from warping as their edges start heating, they are slotted every 6" or so for a distance of say 4".

A proposed practical construction for commercially heating sheet steel by this process is given in Fig. 16.

The writer believes the method is sound in principle and deserves to be developed to a commercial stage.

Versatility of Inductive Heating

Modern developments of electron tubes, gap oscillators, inductor type generators and wire wound generators make possible the production of alternating and oscillatory currents of many amperes and at frequencies ranging from one meter wave length to thousands of kilometers. The perfection of the power condenser makes it possible to so arrange circuits that the generator of a high or medium frequency e.m.f. need supply the power component only of the kv-a. developed. As frequencies are made higher and higher, inductive effects, both electromagnetic and electrostatic, become more and more pronounced. Ultimately all power generated is either radiated into space or converted into heat. When means are devised to concentrate the heat developed in a particular confined portion of space or in a selected mass of material, a rise of temperature results. This temperature rise may be made to continue until all known refractories give way, even graphite turning to vapor. The latter has been actually done in a graphite chamber ¾ of a cubic foot in volume.

The technical means of doing these things have been so perfected and the efficiencies in making desired energy transformations have been so improved that it may be said that all heating of every kind can be done by induction and very frequently with economies which justify its use in industry.

The expression of these thoughts reveals how versatile is inductive heating and how it is only possible in a single paper to more than touch lightly upon the most obvious commercial uses. Thus, in addition to the inductive processes given above for heating solids may be listed the following which are but a very few of those which have been brought to my notice:

a. Removal of tires from locomotive wheels.
b. Heating brake drum rims while revolving and being filled with molten cast iron.
c. Heating ends of valve castings for upsetting and forging.
d. Heating bolt stock before entering heading machine.
e. Heating nickel-chrome billets, rods and wire for swaging, reduction by rolling and wire drawing.
f. Heating ends of shafts to be butt welded.
g. Heating rings, etc. for making shrink fits.
h. Heating ball bearing races for hardening.
i Heating ends of large diameter billets for upsetting or forging.
j Heating tool-steel dies.
k. Heating central region of disc auto wheels for punching.

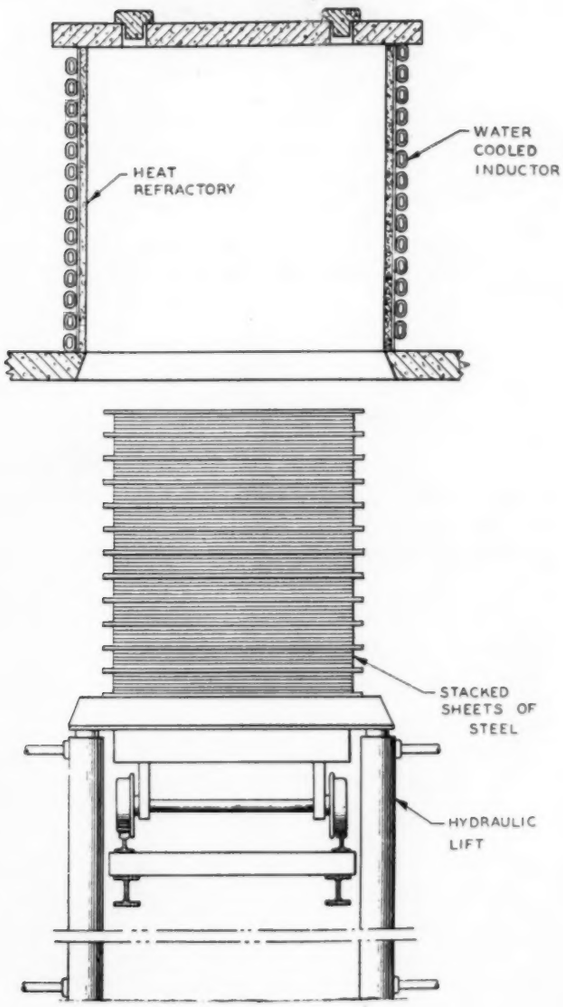


FIG. 16

The above list might be lengthened until it included a very large cross-section of modern industrial processes which employ medium and high temperatures.

The general character of material to which inductive heating may be best employed may be summarized thus:

a. The metal pieces to be heated best should have a certain symmetry of form.
b. Large diameters are favorable to the inductive method.
c. Magnetic metal is cheaper to heat than non-magnetic.
d. The ratio in economies of inductive to fuel heating increases with increase in the final temperature demanded.
e. For extremely fast heating, the inductive method is unexcelled.
f. Localized heating of a part of a large metal piece is most readily accomplished by induction (arc heating excluded).

Power Factor

Power factor and its cost of correction in relation to frequency has been often discussed in papers which deal with melting metals by high frequency induction. It only remains to remark here that when a solid is to be heated, but not melted, it is practicable to make the coupling between inductor and susceptor much closer than is possible in melting practice. The cost for static condensers, or capacitors, will generally run about one-third of what it is when metals are melted, use of equal quantities of power being assumed for the two cases.

In melting practice, the impedance of the load changes from beginning to end of heat. This calls for mechanism and attention, to change from time to time the number of capacitors across the supply circuit in order to maintain unity power factor on the supply line.

In heating solids, on the contrary, the impedance of the load is most generally substantially constant and the number of capacitors installed does not need to be changed while heating is in progress. The power factor correcting feature of an installation is both inexpensive and requires no attention during operation.

Investment and Operating Costs

In preparing for inductively heating solids, the investment costs will involve:

1. Electrical equipment for supplying high frequency current, motor generator set with panels and controls.
2. Capacitor units for controlling the power factor of the supply line.
3. Local wiring, busbar installation, and piping for cooling water.
4. The inductor heaters and
5. The design and construction of mechanical mechanism to handle and move the material to be treated.

This last will add a considerable engineering charge.

Unlike melting furnaces, there is no possibility of standardizing the heaters. Each and every case needs special consideration, specially contrived inductors, and individually designed handling mechanism to meet local conditions, quantity, size and shape of material to be heated and temperature requirements.

The electrical equipment to supply (in most cases) the needed one thousand cycle current and the capacitor units for adjusting power factor may be standardized and will serve equally well for the melting of metals and for heating metallic solids below the melting temperature. Where an electrical equipment for melting is already installed, the additional expense for inductors, etc. is small to make the equipment adaptable to the heating of solids.

Attention is called to the more or less permanent character of all equipment used for either melting metals or heating solids. Unlike other methods of heating, the only thing which becomes very hot is the material treated, and hence no deterioration or destruction from heat can happen (as is often the case with fuel fired heaters and arc furnaces) to the installed equipment. The investment cost for inductive heating is high, but the equipment is usable, without major repairs, for many years and should pay for itself several times over before it is ready for discarding.

Having painted in this and many other papers a picture of the wide spread usefulness and effectiveness of inductive heating, I shall close with the telling of a vision ever present in my mind for the past decade.

A Vision

I see realized in due time a far flung development in Detroit, in Pittsburgh, in Cleveland, in Chicago, in all great industrial centers, where vast numbers of kilowatts are used daily for forging, for annealing, for normalizing thousands of tons of metal and for melting other thousands of tons of ferrous alloys, and all manner of non-ferrous metals. What is this development?

At a centralized great generating station, run with coal, gas or water power, I see huge generators direct connected to prime movers which supply to a widely spread network carried in multiple cables under a single sheath, polyphase, one thousand cycle power. I see this power going to every important place where lighting and heating of any kind whatever is done. I see every melting unit and every type of muffle furnace, every billet and sheet heater, every odd and special type of laboratory and commercial inductive heater, permanently fitted with its unchangeable quota of corrective capacity to bring the phase to near unity on the incoming lines. I see a moderate size bank of capacitors in the great power house, the units of which automatically switch on and off to take all the burden of the wattless component of the kv-a. on themselves and leave the great thousand cycle machines the duty of supplying power only—power which flows out from the central station to be wholly consumed in a countless variety of useful, cleanly, efficient and controllable heating and lighting devices. No more in the region supplied will metals and alloys be poisoned with deleterious matter, and no more will hundreds of tons of surface oxides fall from heated steel.

This vision must become reality for it is sound engineering, it is good economy, it is efficiency, it is progress.

Discussion

Discussion Presented by

W. Dudley, Electrical Engineer, National Tube Co., Pittsburgh, Pa.
Dr. E. F. Northrup, Vice-President and Technical Adviser, Ajax Electrothermic Corp., Trenton, N. J.
L. J. Reed, Asst. Chief Engineer, Jones & Laughlin Steel Corp., Aliquippa, Pa.
C. O. Franklin, Asst. Elec. Supt., Carnegie Steel Company, Munhall, Pa.
S. B. Terry, Asst. Manager, Gage Division, Pratt & Whitney Co., Hartford, Conn.
R. R. Owen, Engineer, General Electric Company, Wheeling, W. Va.
R. N. Blakeslee, Jr., Secretary, Ajax Electrothermic Corp., Trenton, N. J.
J. W. Bates, Electrical Engineer, American Sheet & Tin Plate Company, Pittsburgh, Pa.

W. Dudley: I would like to ask Dr. Northrup if he can tell us the rate at which the heat will soak into the center of a billet. He touched on that subject this afternoon, but I would like him to tell us a little more definitely the time required to heat up the center.

Dr. E. F. Northrup: Your question is rather difficult to answer without experimental data before me to refer to. The principle involved is this, the higher the frequency the less is the depth that the heat current penetrates into the billet. The heat generated in the outer layer of the billet must find its way to the axis by the ordinary process of thermal conduction. It is my understanding that in the case of steel the movement of heat is roughly ⅛" in five minutes. Nevertheless it is always possible to so arrange matters by choice of frequency, rate of heating, etc., that a billet may be uniformly heated to its axis. Practically a billet 3" in diameter, for example, can be inductively heated with 1000 cycles and reach substantially a uniform temperature from surface to axis in about two minutes. If more rapid heating is required, the billet can pass from the inductor coil into a well heat-insulated cylinder where it remains long enough so that, by a soaking process, its temperature becomes uniform before it is delivered to the forging machine.

In the case of heat treating large diameter steel rolls it is desired to heat the surface of the roll much hotter than the axis just before quenching.

This is easily accomplished by the inductive method, generally by regulation of the rate of energy input to the roll.

L. J. Reed: I would like to ask Dr. Northrup whether he can tell us how many pounds of steel can be heated per square foot of heating surface per hour?

Also, if he would describe a little further what type of non-oxidizing gas he would propose for use in strip heating?

Dr. E. F. Northrup: Answering the last question I would state that the type of gas used can be selected by users of the equipment as seems best to them. I understand there has been recent developments in gas made by cracking ammonia, which proves to be a rather cheap type of gas. This gas is free hydrogen and nitrogen mixed. In the test we made we did not actually use any gas as the gas in no way affects the number of heat units required to produce a certain result. I think persons familiar with steel manufacturing would have no difficulty in selecting a gas which would be most suitable for any given purpose of operation. As to the square feet of sheet you can heat in a minute, this depends on the kilowatts you have at your disposal. If the sheet is passing through a muffle, it is theoretically possible by using sufficient power and making the muffle long enough, to heat the sheet at any rate desired.

C. O. Franklin: I would like to ask Dr. Northrup a few questions. At what voltage is this high frequency current generated? Why was the frequency of 1000 cycles selected; was it determined experimentally? Is not greater depth of penetration secured with lower frequencies?

Dr. E. F. Northrup: In standard equipments we make use of a generator which supplies 1000 cycle current at 800 volts. Our condensers for correcting power factor are taped across the extreme ends of the coil. The two lines from the generator with 800 volts between them are taped into the coil, each a small distance from the end of the coil. The coil itself thus behaves in the manner of an autotransformer giving any voltage in the limits 800 to 1200 volts, which is the highest voltage desirable to use in the condensers. This change of voltage at the terminals of the heater coil is effected by taping the generator lines into the coil at different places. Since the power absorbed by the heater is proportional to the square of the voltage at the terminals of the coil, the power taken by the heater can in this manner be varied in the range from the square of 8 which equals 64 to the square of 12 which equals 144.

The power factor of the generator line is brought to unity by selecting the proper number of condenser units, which are connected to the terminals of the heater coil.

It is to be noted that in the circuit of the type used an adjustment of power factor can be made independently without modifying the power adjustments. Power factor and power delivered are independent variables and can be varied in a manner to make both the power factor and power delivered what is desired in a very simple way.

C. O. Franklin: That answers the question of voltage, but why was the frequency of 1000 cycles selected?

Dr. E. F. Northrup: Standard condensers in this country for use of high frequency current are built for a maximum voltage of 1200 to 1250 volts. Two of these condensers connected in series would permit 2400 volts to be used at the terminals of the coil. So far we have thought it was safer and easier to deal with large currents instead of high voltages and so 1200 volts was chosen rather than go to twice this voltage and connect condensers in series.

From the standpoint of low line loss, the higher voltage is desirable. On the other hand much greater precautions have to be taken with higher voltages to protect the furnace from voltage breakdowns and make it safe to operate.

C. O. Franklin: I am still interested in knowing why the frequency of 1000 cycles was selected.

Dr. E. F. Northrup: A certain frequency higher than 60 cycles is required to give satisfactory operation from the technical standpoint. It hence becomes necessary to use a frequency changer. If the frequency changer is used, the generator can be made up to 1000 cycles using the ordinary type of alternator construction. However, the higher the frequency asked for, the greater is the cost of the generator. On the other hand, the higher the frequency the less number of condenser units are required to correct the power factor. From an economic standpoint that frequency is best which makes the sum of the cost of the generator, which supplies the power component, and the condensers which absorb the wattless component, the least. A study of prices and experience has shown that this and other connections are best made by using 1000 cycles or thereabouts. Several years ago I advised our European associates that 1000 volts would be the optimum frequency to use. Nevertheless many different frequencies were tried from 500 cycles up to frequencies much higher than 1000 cycles but now practically all machines for large power use, are built to furnish current, in Europe as well as in America, at about 1000 cycles.

S. B. Terry: I would like to ask Doctor Northrup a different question. He spoke of induction heating chromium plate to make it non-corrosive. We know chromium is a porous metal. Can you tell me or suggest anyone to tell me why induction heating produces a condition in the chrome plate that is non-corrosive?

Dr. E. F. Northrup: I think you can get the best advice on this subject from Mr. R. B. Heppenstall of the Heppenstall Company. They have studied carefully the effect of heating chromium plated steel by induction. It is their opinion that if the steel is heated by induction so the metal is heated beneath the chromium plate, the latter blends or migrates into the steel being 100% chromium on surface and blending off into steel at a slight depth beneath the surface. Extensive experiments have shown that this treatment closes up microscopic pin holes so that the chromium plate becomes highly protective against corrosion. It is thought by most persons that this desirable result can only be obtained by inductively heating the chromium plated material. I am inclined to believe before this conclusion is finally reached that careful experiments should be made in heating the chromium plated material in the right type of muffle furnace and in a strictly non-corrosive atmosphere. Dr. Lester of the Watertown Arsenal has studied these chromium

plated steels and made some very interesting micrographs.

S. B. Terry: I have tried direct heating of chromium plated steel of various thicknesses of plate. It was a fine agent to keep the metal clean for when it came out of an ordinary furnace you could peel the plate right off.

Dr. E. F. Northrup: What precautions did you take?

S. B. Terry: We did not have a controlled atmosphere, but it was a high temperature furnace.

Dr. E. F. Northrup: I would like to see a carefully made test in an ordinary muffle furnace where there is no chance for oxidation—possibly in a hydrogen atmosphere.

S. B. Terry: Possibly I could get that done at General Electric.

W. Dudley: This paper of Doctor Northrup's has been interesting from a number of viewpoints. Not alone has he described what appears to be a very useful tool for heating steel, as well as other materials possessing electrical conductivity, and one which seems to have interesting possibilities, but it was also very interesting from the very human way in which the subject was treated. Apparently the author has studied the problem of heating materials electrically from the viewpoint of the user as well as the scientist, which may be one very good reason why his proposals have been received with such evident interest by this audience of steel mill engineers.

One important feature in the heating of steel by means of a high frequency induction furnace will be the unit charge for electric energy compared with fuel costs for gas heating. During the few hours available I have taken the trouble to dig into the records in an effort to obtain some actual mill figures which may be of some interest to the author of the paper as well as the members.

In a natural gas fired heating furnace operating at about 2500° F., the monthly consumption of gas averages 2½ million B.t.u.'s per gross ton of steel. Perhaps that record is better than many gas heating furnaces show, but it is chosen here as a good example of what a high frequency induction furnace will have to compete with in entering the field of billet heating in which tremendous possibilities may exist. The 2½ million B.t.u.'s per gross ton corresponds to a furnace heating efficiency of some 36% which seems a little high, as we would hardly expect more than 33⅓%. However, for the purpose of this discussion we will follow the record as it stands.

To heat a billet to the lower temperature of 2300° F. with gas and at the same heating efficiency will require 1030 B.t.u. per pound of steel. In a certain high frequency induction furnace working on a 4" O.D. pipe with ½" wall and weighing 16.33 lbs. per foot, which was being heated to 2300° F., the energy consumption at the terminals of the high frequency generator was found to be 146 K.W. Hrs. per pound of steel, or 500 B.t.u., which corresponds to a furnace heating efficiency of 75%.

Dr. E. F. Northrup: You do not pay for the power the generator delivers; you pay for the power that comes into the motor.

W. Dudley: I will reach that point in a moment. With gas at $0.25 per M. cu. ft. and having a fuel value of 1,000 B.t.u. per cu. ft. and with a furnace having a heat efficiency as reported for the skelp furnace, the fuel cost for heating billets to 2300° should not exceed $0.57 per gross ton. Using an induction furnace supplied with electric energy direct from the terminals of a high freqency turbo-driven generator in a power house using coal at $2.35 per gross ton and with an overall coal consumption of 1.9 lbs. per K.W. Hr., the fuel charge for high frequency heating should not exceed $0.62 per gross ton of steel.

That is to say, on the basis of fuel costs alone, there should not be a material difference, even in the Pittsburgh district, between heating by gas and by high frequency induction where the size of the installation would justify direct prime mover drive for the high frequency generator.

Of course, the final comparison of overall heating costs between the gas fired furnace and the high frequency induction furnace must necessarily include other items such as labor charges, scale loss, refractories, space requirements, investment costs, etc., and each installation will have to be examined individually. I feel, however, from the figures which have been presented and from consideration of operating costs on gas fired furnaces that where electric energy is available at overall costs below $0.0075 per K.W. Hr., and with 1000 B.t.u. gas costing $0.25 or more per M cu. ft., high frequency induction heating will justify very careful consideration even from an economy viewpoint. This will be evident particularly for new installations where it is not necessary to supplant existing direct fired furnaces.

Dr. E. F. Northrup: I thank the speaker for his analysis of these figures. There is no question but that the largest sales resistance we have to meet in getting high frequency inductive methods accepted, is the high investment cost of the equipment. It should be remarked that the chance comes of doing inductive heating economically from being able to perfectly conserve the heat units which are supplied. Little heat is lost by radiation and otherwise. In the case referred to in the paper of heating razor blades in an inductively heated muffle, it was not contemplated that the economy would exceed that of fuel heat. It turned out, however, that the electrical method was considerably cheaper and the rejects of razor blades were considerably less with the electrical methods.

R. R. Owen: What were the previous gas costs?

R. N. Blakeslee, Jr.: We do not have the cost of gas per cu. ft., but the power cost was ¾ cent per K.W. Hour.

J. W. Bates: Figure 16 shows a method of inductively heating a stack of sheets, utilizing overhanging or protruding copper sheets placed one every few inches in the height of the stack.

It seems questionable to me that the copper sheets would be very effective in transmitting heat up or down through the stack as the heat transfer in this direction is very poor. It is ordinarily assumed that the heat transfer is nine times as great from the edge of the sheet inwards as it is from a sheet to the next sheet above or below it. For this reason it would seem necessary to have every other sheet in the stack a copper sheet if any material benefit is to be obtained. The necessity for using a large percentage of copper sheets would make this method of annealing uneconomical.

Then there is the question of copper flow. It has been my understanding that when copper sheets and steel sheets adjacent to each other are raised to annealing temperatures that an appreciable flow of copper occurs to the steel sheet. This would, in many cases, be very undesirable.

Dr. E. F. Northrup: I think Mr. Bates will have his mind quite cleared up on the proposed method of heating steel sheets with copper sheets placed between steel sheets when he again refers to the paper. The descriptions and diagrams there given, I believe, will make the whole matter very clear. I may add that the method was carefully tested in our Trenton plant and found to work in exactly the manner described in the paper.

The Releasor

By R. J. HARRY
Engineer, Alliance Machine Company, Alliance, Ohio

In every case when steel consumption decreases the demand for improved quality of steel increases. We are now in a period where the demand for high quality steel must be met. In order to meet this quality demand and to obtain a high percentage of practice from ingot to finished product, much experimenting is being done on big end up, hot top ingots. The advocates of this type of ingot claim a higher percentage of yield and superior quality.

Practically all steel plants are at present equipped with sufficient equipment to strip the moulds from the small end up ingots. The ingot stripper used for this purpose being of the standard rope or screw type.

These strippers must have a sufficient lift to raise the mould so that the bottom of the mould clears the top of the ingot, this lift being anywhere from ten to fifteen feet to meet the various demands and sizes of moulds and ingots. The stripping force which is exerted on the ingot by the plunger, which engages the top of the ingot, is exactly opposed by the force exerted on the mould through the lifting arms which depend from the stripping mechanism and are attached to the mould by means of suitable lugs. For large size ingots the normal stripping force of the stripper must be at least 200 tons to take care of stickers. Ingot moulds that are cracked or have very rough interior surfaces sometimes require much greater than the normal stripping force. The force to strip the ingot loose from the mould, while of great magnitude, need only be exerted over a very short distance as the inside of the mould and ingot are tapered to facilitate stripping and prevent sticking.

Whereas it is necessary to remove the mould from the ingot before it can be sent to the mill to be charged into the soaking pits, it is obviously impractical to handle the large end up ingots in this manner. The large end up ingots are always sent to the blooming mills in their moulds, where they are charged into the soaking pits by the pit cranes. The hot top produces a more homogeneous ingot and facilitates handling. Other advantages accruing to the big end up ingot are conservation of heat and the protection of the surface of the ingot inasmuch as the hot ingot is never exposed to the cold atmosphere except when being taken from the mould and charged into the soaking pits.

This method of handling is satisfactory as long as the ingots are not stuck in the moulds. When a sticker is encountered delays and confusion are bound to occur and much expense is involved in releasing the ingot. With new moulds few stickers are found but as the moulds get older the percentage of stickers increase rapidly.

It was with the idea of supplying an equipment to prevent delays and confusion in the soaking pit building that our company has developed a machine called a Releasor. This is a single purpose machine whose only function is to release the ingots in the mould. This machine has a very short lift as it is not necessary to remove the ingot from the mould.

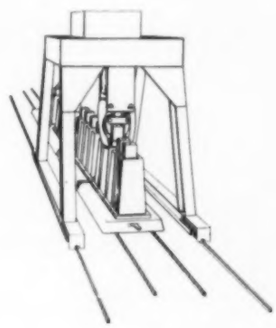


FIG. 1.

The machine is equipped with powerful tongs which engages the hot top of the ingot close to the point where the hot top joins the main body of the ingot. Two members depending from the Releasor engages the top of the mould. These machines are designed to exert a normal force of 100 to 200 tons depending on the size of ingots to be handled.

On account of the tongs and arms operating in the same plane it is unnecessary to raise the Releasor as the machine travels from mould to mould and as a result much greater speed can be obtained than with the present kind of equipment where the tongs and arms operate in planes at 90 degrees to each other.

Since the Releasor is designed to supplement existing stripping equipment and may be called on to handle only a small percentage of the ingots it is hard to justify a very expensive equipment for this work.

Fig. 1 shows this Gantry Releasor. The mechanism is so arranged that it can be lifted high enough to clear the ingots and locomotive. The weight of the machine is such that by driving the four bridge track wheels, greater tractive effort can be obtained than is obtainable with a narrow gauge locomotive. It compares favorably with that of a standard gauge locomotive, and can therefore be used to move ingot buggies if necessary.

This may be necessary where a sufficiently long track for the Gantry Releasor cannot be installed.

In such case the Releasor would loosen all ingots within ready reach, then by the use of special engaging means, move the ingot buggies so as to locate them within reach of the Releasor.

Owing to the fact that the releasing mechanism is located centrally with reference to the ingot buggies no trolley or cross travel motion is required, although it could be easily supplied if found necessary.

This machine can be located adjacent to the open hearth, in the yard or close to the mill, and where sufficient clearance under existing cranes is available it can be located in the open hearth or mill building.

The releasing mechanism can also be located on stationary supports and by means of a locomotive, or car pusher, the ingots can be moved under the releasor and loosened in the moulds.

In summing up the advantages obtained with the use of the Releasor, it can be said that high speed of loosening the ingots in the moulds is obtained. The mechanism is comparatively simple and not costly to maintain. The operator has much better visibility. No runways or building is required. The first cost is only a small fraction of cost of present equipment to do the same work.

ANNOUNCEMENT

TO THE

Membership and Manufacturers of Steel Mill Equipment

▲

At the last board of directors' meeting of the A. I. & S. E. E. held February 24, 1933 it was decided that the

1 9 3 3

CONVENTION

AND

IRON AND STEEL EXPOSITION

WILL NOT BE HELD IN JUNE THIS YEAR

BUT

HAS BEEN DEFERRED UNTIL LATE FALL

DETAILS AND DATES WILL BE ANNOUNCED LATER

THE PROTECTIVE TARIFF WAS NEVER NEEDED MORE THAN IT IS NOW

Advances In Resistance Welding Made Possible With Thyratron Control

By WARREN C. HUTCHINS
Industrial Engineering Department, General Electric Company, Schenectady, N. Y.

Presented before the Pittsburgh District Section of the A. I. & S. E. E., January, 1933.

INTRODUCTION

Thyratron control for resistance welding is—a device which accurately controls the time power as applied to a resistance welder.

Thyratron control is best suited to spot and line welding with alternating current; therefore, this paper will be confined to a discussion of these two phases of resistance welding.

This subject will prove most interesting, I believe, if discussed in the following order:

1. Reasons for developing thyratron control for resistance welding.
2. How Thyratron control has been applied to resistance welding.
3. Outstanding results obtained with Thyratron Control.

This discussion will therefore be divided into three corresponding sections.

I. WHY THYRATRON CONTROL HAS BEEN DEVELOPED

Thyratron control has been developed to fulfill the need for an improved resistance welding control. This need can be best realized by briefly reviewing the conventional method of controlling spot and line welders.

Spot Welding

Spot welding is used for welding the flat surfaces of sheet metal parts together. In this process the double thickness is clamped between electrodes which are usually made of copper. A high impulse of current supplied through a suitable transformer is passed through the joint. At the surface contact of the metal parts, which is relatively high in electrical resistance, heat is generated in such quantities as to bring the parts to a forging temperature. The electrode pressure forces the parts together completing the weld.

In spot welding, there are three main variables:

1. Pressure of the electrodes on the work;
2. The value of current; and the
3. Time of current application.

The pressure can be adjusted to the most desirable condition by varying the electrode compression spring setting, and the current can be adjusted by changing taps on the welder transformer. After proper adjustment of the pressure and current, the heat generated is directly proportional to the time that current is allowed to pass through the joint.

It is very desirable to make resistance welds in as short a time as possible for several reasons among which are:

1. High speed production.
2. Minimum oxidation or scaling (oxidation is a function of time and temperature).
3. To prevent distortion or warping (the distortion becomes a minimum when the heat is confined to the actual welded area and this is possible only if the welding time is very short).

If welded in a short enough time, it is theoretically possible to generate the necessary heat at the location of the weld, fuse the surfaces together and allow the heat to be conducted away by the surrounding metal and electrodes without heating the outer surface of the metal sheets to an injurious temperature.

The early method of controlling spot welders was to manually close the circuit allowing current to pass. When, in the opinion of the operator, the metal was sufficiently hot to complete the weld, the circuit was manually opened. For visual and manual determination of the time power is supplied to a welder, several seconds are necessary. This method, of course, is very crude. Inconsistent results were inevitable, and the welds were badly burned or oxidized.

When long welding times are used, a relatively low current is necessary. As the time is shortened, the current must be made inversely proportional so that practically the same total amount of electric energy is dissipated at the joint in welding heat. In short periods, however, the loss due to radiation and conduction is reduced and slightly less electrical energy will be required.

As an improvement over the manually operated spot welder, the power driven machine was developed. After pressure is mechanically applied to the electrodes, a rotating cam closes a limit switch, energizing a magnetically operated contactor through which power is supplied to the welder. When the limit switch opens, the line contactor is de-energized, thus opening the welding circuit. The time power as applied to the welder is determined by the time the limit switch is closed and can be varied by changing the speed of the cam or by adjusting the raised portion of the cam.

This power driven machine is a great improvement over the manually operated welders. Welding times down to ½-second were made possible, and when adjusted for a welding time of 1-second or more, fairly accurate results were obtained.

Various other types of control, including tube timers, have been developed for timing the excitation of magnetically operated contactors, in an effort to improve welding conditions.

Where it is desired to make consistent welds, and a magnetically operated contactor is used, long welding times are essential. The reason for this is, the mechanical and electrical lag in the limit switch or contactor varies so greatly, the time of power application to the welder is accurate only within two or three cycles. Therefore, the welding time must be

THE PROTECTIVE TARIFF WAS NEVER NEEDED MORE THAN IT IS NOW

increased until the variations of time do not cause an appreciable percent change in the total time that power is applied to the welder.

As an example, let us consider a case where 60 cycle power is used and the current is set for best results when current is applied for 1/10 second, or 6 cycles. If the contactor allows the current to flow 2 cycles more or less than the desired time, the weld will receive 33% more or less heat than is required for best results. Undoubtedly, the weld will be burned, badly oxidized or incompleted.

Now, let us assume that the current is set so that best results are obtained in 1 second or 60 cycles. If the contactor passes two cycles more or less than desired, the weld will receive only 3½% more or less heat instead of 33% as in the previous case, and probably this small error could not be detected in the weld quality. The weld will be badly oxidized, however, and warping will present a serious problem. Maintenance of the contactor tips is another serious problem, especially for large capacity welders.

Three main problems were therefore presented to control engineers, indicating a need for improved control for spot welding machines.

First: To furnish a control which is accurate for both long and short welding periods and easily adjustable to the most desirable welding period.

Second: To furnish a device capable of accurately controlling welding circuits in periods short enough to prevent warping and oxidation of the metal.

Third: To furnish a dependable control—one to stand up continuously without need of frequent repairs and adjustments.

The foregoing applies also to projection welding, a modification of spot welding.

Line Welding

The process of line welding or seam welding consists of passing a double thickness of sheet metal to be welded, between two rolls at a constant speed; pressure of the rolls on the work is adjusted to suit the metal being welded; voltage applied to the rolls is adjusted so that the resulting current through the joint will generate sufficient heat to fuse the metal sheets together, producing a "line weld". In this method of welding, factors other than accurate control of voltage must be considered. For instance:

Assuming electrical power is constantly applied to the electrodes, the parts being welded will require a relatively large amount of current at the start of the weld, it being necessary to raise the metal to a welding temperature from room temperature. As progress is made, the heat will travel ahead of the point of contact, preheat the metal, and less current will be required to produce the necessary welding heat.

Also, if the voltage is set so as to produce a satisfactory weld for the thickest part of the sheet metal, the thinnest section may be burned. It is an accepted fact that there are small variations in the thickness of standard commercial sheet metal.

Also, the current will follow the path of least resistance, and instead of producing a continuous seam of fused metal, it may flow around certain high resistance spots resulting in an imperfect weld.

To overcome these objectionable features, an interrupter is used in series with the welder transformer primary—i.e. a device for making and breaking the electrical circuit rapidly. The line weld then becomes a series of overlapping spot welds, allowing the metal to chill during the off periods, and preventing the building up of heat ahead of the rolls. To assist in cooling the work, water-cooled rolls or a water spray may be used on the work and rolls.

Two outstanding advantages are gained by interrupting the welding circuit:

1. Increased speed of welding.
2. Improved quality of the weld.

The duration of current for each spot being very short, and in view of the metal being allowed to chill during the off periods, the current must be increased many times beyond the value of current used for uninterrupted line welding. Higher momentary voltage is necessary to produce this increased current, and is usually sufficient to break down the high resistance spots, thereby producing a continuous seam of fused metal. With this process, a line weld can be started and completed, welding both the thin and heavier sections of the sheet metal with one heat setting.

The necessary rating of a line welding machine depends upon the thickness of the metal to be welded and the speed at which it is welded. The usual ratings are from 25 Kv-a to 300 Kv-a (300 Kv-a equals 100,000 amperes at 3 volts).

It has been found that when line welding sheet metal containers, 8 to 12 spots per inch are required for best results; therefore, the maximum rate at which the current can be interrupted, determines the maximum speed at which the work can be welded.

To obtain welding speeds which are most economical and in turn suitable for industry, it is necessary to make several hundred interruptions of the current per minute. Just imagine the contactors or control that would be necessary for rapidly interrupting circuits carrying several hundred Kv-a. To do this mechanically, is difficult if not entirely impossible. Fair results have been obtained up to 300 interruptions per minute or more provided the rate of power input to the welder did not greatly exceed 35 Kv-a. Assuming 10 spots to the inch, 300 interruptions per minute, will permit a maximum speed of 30 inches per minute. 35 Kv-a, however, will weld only very thin stock at this speed—24 or 28 gauge. The interruptions were usually accomplished by using belt-driven or induction motor driven cam operated contactors. Also, a number of devices have been developed which will interrupt welding circuits 900 or more times per minute for low capacities. The results are not entirely consistent or satisfactory for several reasons, they being:

1. Mechanical devices operating at these high speeds will wear rapidly and produce variations in the time the contactors are closed, necessitating frequent adjustments.
2. It is impossible to prevent arcing at the tips because the contactors seldom open at the zero point of the current wave. The result is very noisy operation and inconsistent welding times, and in turn inconsistent welds.

3. The contact tips will wear and pit rapidly because of battering effect and arcing at the tips.

Efforts have been made by many manufacturers to perfect mechanical contactors which would close the circuit, measure out the desired number of cycles, then open the circuit at the zero point on the current wave for the desired number of cycles. By using a synchronous motor, driving a cam operated contactor, similar to the device shown in Fig. 1, this has been accomplished with some degree of success. With this arrangement, however, there are several difficulties which apparently cannot be overcome:

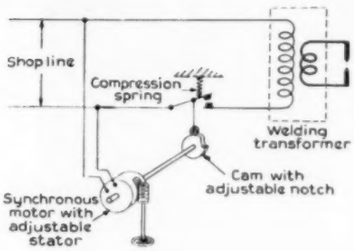


FIG. 1.

1. They are limited in capacity, and speed, at which they can interrupt the welding circuit.
2. They require very careful adjustment and frequent readjustments.
3. They have a high maintenance and repair cost. Contactors for this service are often submerged in water for cooling. To make repairs, necessitates costly non-productive delay.
4. The slight variation in thickness of metal being welded, and variations of the surface conditions of the metal, cause changes in the amount of electrical resistance in the welding circuit. This changes the power factor of the welding load and in turn varies the relation of the current wave to the voltage wave. The contactors are opened in synchronism with the voltage wave. Therefore, when the power factor changes, the current wave shifts its relation to the voltage wave causing the contactor to open when the current is not zero. The result is sparking at the contactor tips and an occasional arc-over, which renders the device useless until repairs or replacements of the contactor tips have been made and the unit has been readjusted.
5. Another disadvantage of the synchronous motor driven contactor is that it cannot be easily and quickly changed from one duty cycle to another. To change its speed of interruptions, necessitates changing the gear ratio between the motor and the cam. To change the ratio of "on" to "off" time requires very careful adjustment of the raised portion of the cam.

There is one large automobile manufacturer who found that during normal operation, the contactors for his line welders had to be replaced once every 8 hours to insure reasonable satisfaction. This does not represent an unusual condition, but is typical of a great many installations today.

Five main line welding problems (including those mentioned under spot welding) were therefore presented to control engineers, indicating a need for improved control for line welding machines.

First, to furnish a control which is accurate—one that will positively close the welding circuit, measure out a definite number of cycles for the "on" period, then open the circuit, measure out a definite number of cycles for the open circuit period, and again close the circuit; repeating this cycle of operation until it is desired to make a change.

Second, to furnish a control suitable for interrupting the welding circuit at any desirable frequency.

Third, to furnish a control which is flexible, i.e.: easily adjusted to the most desirable duration of "on" and "off" periods.

Fourth, to furnish a dependable control—one that will stand up continuously without need of frequent repairs or adjustments.

Fifth, to furnish a control with ample capacity for any size of welding machine.

These problems have been solved by our engineers by properly applying tube type, mercury vapor, grid controlled rectifiers, known as Thyratron tubes.

II. THYRATRON CONTROL APPLIED TO RESISTANCE WELDING

Thyratron Tube

A brief description of the Thyratron tube and its characteristics will assist in understanding its application to resistance welding. The Thyratron tube is, in effect, a check valve for electric current, automatically passing current in one direction only, and capable of preventing flow in either direction. In the tube there are three major elements: Namely, the anode, cathode, and grid. Fig. 2. All three are within the tube which is filled with mercury vapor or some inert gas. The Thyratron tube will conduct

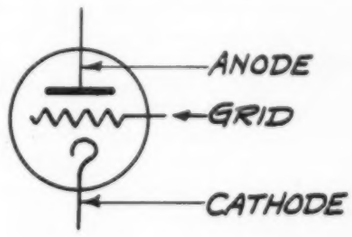


FIG. 2.

current in one direction only and that from the anode to the cathode. Picture the tube with the anode and cathode an inch or so apart with the grid between. Provided the grid is held at a voltage sufficiently negative with respect to the cathode, a relatively high positive voltage can be applied to the anode with respect to the cathode without conduction of current. While this high anode voltage is applied, the grid voltage may be increased positively with respect to the cathode and at a certain critical grid voltage, the mercury vapor will ionize and current will flow between the anode and cathode.

Therefore, by properly controlling the grid volt-

age, the tube can be made to begin passing current at a predetermined instant.

The grid cannot stop the flow of current, but if the current ceases to flow long enough for deionization to occur, the grid can regain control and prevent the current starting again. If an AC voltage is applied to the anode and cathode, the grid has an opportunity of regaining control once each cycle, and can delay the start of the current flow for as long a period as the grid is sufficiently negative with respect to the cathode.

Thyratron Control for Line Welders

Let us consider a line welder where the current is rapidly interrupted. Fig. 1.

Where Thyratron control is used, the mechanical interrupter is replaced by a series transformer (Fig. 3), the primary being wound for line voltage and frequency. The capacity of this series trans-

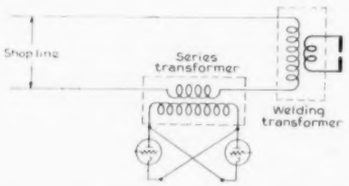


FIG. 3.

former should be equal to the welder capacity. Connected across the high voltage secondary of this series transformer are two Thyratron tubes so arranged that one passes current during half of each cycle, and the other passes current the other half of each cycle, when the grid voltages are sufficiently positive with respect to the cathodes.

When the Thyratron tubes are not passing current, the transformer introduces a high reactance in series with the primary of the welder transformer, which allows only the exciting current of the series transformer to be supplied to the welder. This exciting current is only about 5% of the full load rating of the welder and is negligible with respect to welding.

When the tubes are passing current, the secondary of the series transformer is literally short circuited, decreasing the impedance of the series transformer to practically zero. Thus, the series transformer becomes a very good conductor impressing approximately 95% of full line voltage across the terminals of the welder.

It is, therefore, apparent that by properly controlling the grid voltage of each tube, it is possible, in turn, to control the duration of the "on" period for welding, to any exact number of cycles. Likewise, the "off" period can be controlled to a desired number of cycles.

The grids of the two large Thyratron tubes are controlled by an auxiliary circuit which produces a synchronously timed oscillating voltage in the following manner:

A condenser is charged with direct current through a very high resistance. The voltage across the condenser gradually builds up until it reaches a peak voltage, at which instant a small Thyratron tube connected properly in the circuit discharges the condenser to zero voltage. As soon as the condenser has been discharged, the tube stops passing current and the condenser begins charging again. The charging rate of the condenser can be varied by changing the amount of resistance through which the condenser must be charged and by changing the capacity of the condenser being charged. The frequency of this oscillating circuit can, therefore, be varied greatly.

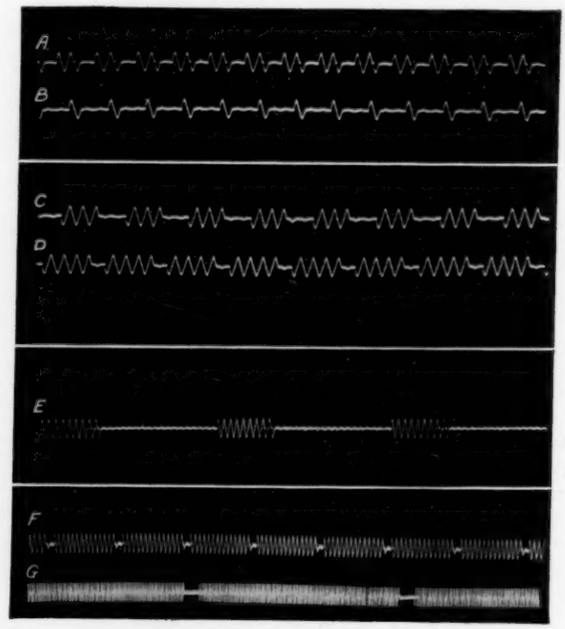


FIG. 4—Oscillograms Illustrating Range of Control to Be Obtained with Thyratron Tube Control for Resistance Welding Machines.

If the AC voltage of the main power supply to the resistance welder is super-imposed on the grid of the timing tube, the oscillations of this circuit become synchronously timed with the alternating

FIG. 5—Thyratron Welding Control Panel with Synchronous Tube Timer.

current power supply. This auxiliary circuit is known as the Thyratron synchronous timer and accomplishes the desirable results of properly controlling the grids of the large tubes. The large Thyratron tubes in turn accurately control the time that power is applied to the welder.

Consequently, the first control problem, that of accuracy, is solved. Fig. 4. (For more details of the timing circuit see page 95).

The second control problem was to furnish a device suitable for interrupting welding circuits at any desirable frequency. When operating on 60 cycle power, Thyratron control is used for accurately interrupting line welding circuits for any rate from 30 up to 1800 times per minute. Interruptions up to 7200 times per minute are possible when used with 240 cycle power.

The third problem was to furnish a flexible control. On the face of the panel Fig. 5, there are dials provided for varying the resistance through which the condenser is charged in the timing circuit. Snap switches are provided which permit cutting in or out condensers in the timing circuit. By changing either of these adjustments, the frequency of the voltage oscillations in the timing circuit is changed, which in turn changes the rate of interrupting the welding circuit. Therefore, by dial and switch adjustments, which are no more difficult than tuning in a local station on your radio, the operator can quickly set the control for any desired duration of "on" period from 1 cycle up to 60 cycles or more, with an equal or different number of cycles for the "off" period.

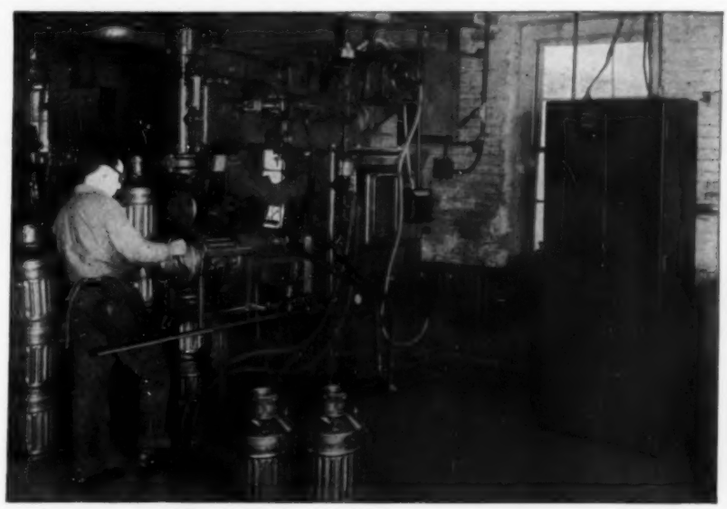


FIG. 6—Oil Cans Being Line-Welded on Machine Operated with Electron Tube Control.

The fourth problem was to furnish a dependable control to operate continuously without need of frequent repairs or adjustments. The Thyratron tubes where used in resistance welding have an average expected life of 10,000 hours of continuous operation, or the equivalent of operating 8 hours a day for more than three years. Usually, adjustments need be made only when it is desired to change the welding cycle.

The fifth problem was to furnish a control suitable for application to any size welding machine. Thyratron control is already in use for capacities ranging from 10 Kv-a up to 700 Kv-a. For greater capacities, it will only be necessary to use a larger series transformer and larger Thyratron tubes.

Thyratron Control for Spot Welders

For spot or projection welders, the Thyratron control is very similar to the control for line welders. The main difference is an arrangement which allows only one impulse of power to be applied to the welder, after the spot welding electrodes have been clamped on the work. The duration of "on" time is adjustable to any desired number of cycles from one cycle up to 60 cycles or more. The spot welding panel may be operated as a line welding control by merely changing the position of one switch.

Thyratron Control for ½ Cycle

In addition to the Thyratron Controls already described, our engineers have developed another Thyratron Control which permits spot welding in only ½ cycle. The series transformer is eliminated with this ½ cycle control and only one large Thyratron tube with a few small tubes are necessary. This control is suitable for capacities up to 300 Kv-a or more. It is expected that this ½ cycle control will permit greater spot welding speeds and make possible higher quality welding of some alloys, especially in a very thin gauge stock, than is possible with any other control.

Other Advantages of Thyratron Control

Where a welding machine equipped with Thyratron control is used for welding various thicknesses of material to fulfill "short orders", adjustment will probably be necessary for each gauge of stock. After having been properly adjusted for one thickness of stock, the heat setting of the welder, and the dial and switch settings of the Thyratron control can be recorded. At some later date a repeat order for welding that same material can be filled by readjusting the welding equipment to agree with the records for that material.

Thyratron control functions without noise.

After a satisfactory welding cycle has been established, thyratron control will repeat that cycle of operation as long as there is welding to be done

The control is completely protected by a steel enclosing case, making it absolutely suitable for industrial application.

There are no moving parts to necessitate adjustment, replacement and general maintenance.

All contactors for making and breaking the welding circuit, water-cooled or otherwise, are eliminated.

III. OUTSTANDING RESULTS OBTAINED WITH THYRATRON CONTROL

A great deal of the following information is made available by Mr. R. T. Gillette of our Works Laboratory in Schenectady, who is in charge of all resistance welding processes and methods used in the General Electric factories in Schenectady.

Mild Steel—Spot Welding

A large radiator manufacturer experienced a great deal of difficulty in chromium plating automobile radiator shells at the location of spot welds. The reason for the difficulty was that the plating would not adhere to the oxidized surface of spot welds made in the conventional manner. Had Thyratron control been used, the heated area would have been confined to the inner surfaces of the two parts being welded, preventing discoloration or oxidation of the outer surfaces. To accomplish this, the duration of power application to the welder must not exceed 1 cycle, and for very thin gauge stock, the time must be kept to a half cycle.

Spot welds are being made on 1/16" stock using one large flat electrode and one pointed electrode with small flat area. Where Thyratron control is used, and the duration of power application to the welder does not exceed one cycle, a full strength weld is made without any apparent distortion or discoloration of the surface next to the flat electrode.

Stitch Welding with Spot Welder

In one of our factories, engineers have developed a machine for making spot welds at the rate of 600 per minute. This has been made possible only through the use of Thyratron control. It will be used for stitch welding thin sheet metal containers with square corners where a line welding machine cannot be used. Elkonite electrodes will be used and the duration of power application will be only one cycle for each spot weld. The welding machine will be driven by a synchronous motor which automatically maintains the following sequence of operation. An instant after the electrodes have been clamped on the work, the thyratron control will allow one cycle of power to pass, after which the electrodes will be lifted from the work for approximately one and one-half cycles, allowing the work to be shifted a slight amount before the next operation. Excellent results have been obtained on mild steel, and this welding process will eventually be used for welding terne plate, which is a mild steel coated with lead and tin.

Line Welding

Recently, there was a manufacturer experiencing difficulty in welding 22 and 24 gauge low grade steel in the manufacture of oil and grease containers. Although the tests required that the product stand up under a pressure of only 25 lbs. per square inch, there was a high percentage of rejects. The speed of welding was approximately 70" per minute. This company requested us to make sample welds using Thyratron control, improving the quality of the welds so that leakage would not occur at a pressure below 50 lbs. per square inch, and to increase the welding speed if possible. The results obtained by Mr. Gillette in our Works Laboratory using Thyratron control were astounding. The thyratron control was set for 1800 current interruptions per minute. The speed of the rolls was set for 180" per minute. The result was 10 spots to the inch, producing a joint of excellent quality. These welds made at 180 inches per minute would not fail at 400 lbs. per sq. in. pressure.

It is within the realm of possibility that, if Thyratron control is used with 120 cycle power instead of 60 cycle power, and 10 spot welds to the inch are made, we will be able to weld at a speed of 360 inches per minute, or 30 feet per minute. With 240 cycle power, 60 feet per minute should be practical.

Duralumin (17-ST)

Working jointly, a series of experiments have recently been completed by a manufacturer of aluminum, a manufacturer of automobile accessories, and a manufacturer of resistance welding equipment, using Thyratron control for line welding aluminum and its alloys. The results have been encouraging. Water tight seams have been made with soft aluminum sheets, and 17-ST, or duralumin sheets, the high strength aluminum alloy.

In a joint report by these three companies, it is stated that successful results have been obtained when line welding 17-ST and soft aluminum sheets in thicknesses from .032" to .101", which was the capacity limit of the welding equipment used.

It is further stated in this report that Thyratron control with a synchronous timer is the only method known for obtaining these satisfactory results.

Dow Metal

It is a known fact that dow metal, a magnesium alloy, can be spot welded, but it is often thought to be impossible to get consistently good results. It is our opinion confirmed by actual experiment that the application of Thyratron control will be an important factor in solving this problem.

Terne Plate

Terne plate—a mild steel coated with lead and tin—is being used widely for automobile gasoline tanks. For approximately two years, efforts were made by a large automobile manufacturer to determine the best device for satisfactorily line welding this metal at an economically high speed in the production of gasoline tanks. I would like to quote from an article entitled "Welding Processes in Building Ford Cars," appearing in the June 16 issue of "Iron Age." In reference to the fabrication of gasoline tanks by the line welding method, the article states that the older mechanical type interrupters made possible welding at a maximum rate of 38" a minute. The article then goes on as follows:

> "The particular new feature in this seaming operation is the application of Thyratron tubes. Seaming is now done at the rate of 68" a minute. The expectation is that this seaming speed may be brought to double and perhaps more than double that when using air break contactors, with the added advantage that the noise of the mechanical current breakers is eliminated.
>
> "An important fact of the thyratron control is that it can open and close the welding circuits at the zero point of alternating current wave. That being the case, it became immediately desirable to determine the optimum number of complete cycles that would give desirable results. Tests showed that a good weld was produced by welding spots which were 5 cycles in duration. Present practice accordingly allows the current to be on for 5 cycles and off for 2 cycles. There

being 3600 cycles in a minute, there are thus 514 interruptions in a minute. With the material welded moving at a rate of 68" in a minute, there are nearly 8 welding spots to the inch."

This automobile company is now using a large number of thyratron control equipments for this work.

Chromium and Cadmium Plated Steel

Experimental welds show that steel can be satisfactorily welded through chromium and cadmium plating if the time of power application is accurately controlled with Thyratron control equipment.

Stainless Steel

Among the metals most talked of today, and among the metals which make possible the fabrication of lighter weight structures and corrosion resisting containers and pressure vessels, stainless steel is very prominent and should be near the top of the list relative to importance. It is often referred to as 18-8, which represents the percentage of chromium and nickel respectively. Its peculiar characteristics have for years prevented its general use, in that it could not be welded so as to maintain its full strength and corrosion resisting characteristics. It can be gas or arc welded, but to restore neat appearance, full strength and corrosion resistance, welding must be followed by expensive buffing and heat treatment operations. The use of Thyratron control has apparently solved these problems and stainless steel can now be either spot welded or line welded, maintaining its characteristics without need of further treatment or buffing.

Some of the characteristics of 18-8 are:

1. Corrosion resisting, as its name implies.
2. Physical properties excellent.
   (a) Annealed:
   Ultimate tensile strength—
   80,000 to 100,000 lbs. per sq. in.
   Elongation in 2"—68%
   Reduction in area—65%
   (b) Cold worked:
   Ultimate tensile strength—
   150,000 to 200,000 lbs. per sq. in.
   Elongation in 2"—18%
   From this data, it is obvious that stainless steel is very ductile and suitable for working into practically any desired shape.
3. Electrical resistance is 7 to 12 times that of mild steel.
4. Stainless steel is annealed or softened by quenching from approximately 2000 deg. F. For thin gauge metals, air quench is sufficient.
5. If the temperature is raised to 1400 or 1500 deg. F. a radical change takes place in the grain structure of the steel in only a short time. Chromium carbide precipitates, leaving the metal with an appreciable reduction in chromium, rendering it non-corrosion resisting. When at this critical temperature, the iron, chromium, nickel and carbon will become a mixture, and when cooled, the physical strength of the metal will be reduced appreciably. If this same metal, however, is heated to a temperature of approximately 2000 deg. F. and quenched, all of the desirable characteristics of annealed stainless steel can be reinstated.

Consider spot welding of stainless steel. If it is welded on the conventional type of welder in one second or more, the metal at the point of fusion reaches approximately 2500 deg. F.—the temperature at which it is plastic. In all directions from the weld, there will be a zone which reaches only the critical temperature at which carbide precipitates and the various metals separate to form a mixture with the carbon, Fig. 7.

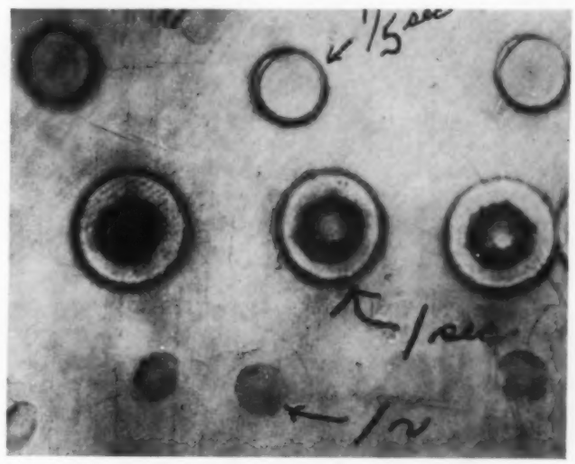


FIG. 7.

It has been proven that if the metal is quickly heated to a temperature at which carbide precipitates rapidly—1400 to 1500 deg. F.—and is quickly cooled, all in a short enough time, the desirable physical properties of the metal, and its corrosion resisting characteristics will be maintained.

When thyratron control is used with a spot welder and the time of power application is adjusted for only one cycle or 1/60th of a second, a weld of excellent quality can be made on stainless steel without carbide precipitation or discoloration on the outer surface of the steel, Figs. 7 and 8. The strength of a spot weld made in one cycle is sufficiently strong to pull a hole in one sheet or the other when the two welded sheets are torn apart. Also the weld can be twisted through an agle of 90° before failure occurs.

Interesting results were obtained with an oscillograph in determining the amount of power input to this one cycle weld, Fig. 8. The thickness of the stainless steel is .037 inches. The power measurement was taken directly across the electrodes and does not include the losses in the resistance welding transformer. The approximate power required was 26,000 amperes at 1.7 volts for one cycle. The total power consumed for one spot weld was 737 watt seconds, which indicates that 2400 spot welds on this stock would consume only one cent's worth of power at two cents per KW-hour.

During this same experiment, mild steel of the same thickness was welded and the power consumption measured. It is interesting to note that 830 watt seconds were required for mild steel compared to 737 watt seconds for stainless steel. This shows

that on mild steel, 2100 welds will consume only one cent's worth of power. For welding stainless steel, it has been found that one of the medium grades of Elkonite makes the best spot welder electrodes.

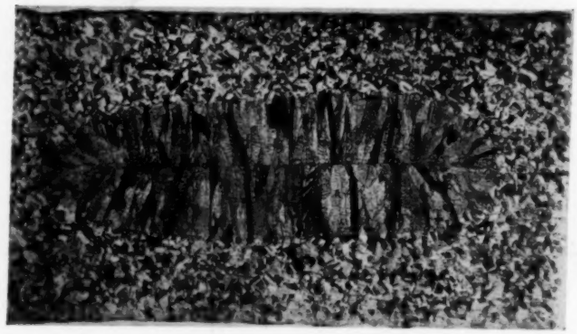
Line Welding of Stainless Steel

When line welding stainless steel, the Thyratron control is equally essential as for spot welding this metal. When thyratron control is used, each one of the overlapping spots are completed without heating the outside surfaces of the two plates to an injurious or discoloring temperature. This is accomplished by adjusting for one cycle duration of power application to each overlapping spot weld. The "off" period should be approximately 2 cycles, and the work moved at a speed so that there will be twelve to fourteen overlapping spots to the inch. Best results are obtained when water is sprayed on the top and bottom sides of the work and rolls while the stainless steel is being welded. This method permits welding at a speed of 80" per minute.

A very satisfactory method used in our own Laboratories for testing line welds is to weld around the four sides of a square or rectangular pair of sheets in the flat position. After they have been line welded, a hole is drilled in one of the sheets and a pipe nipple is welded on so as to permit application of hydraulic pressure. By gradually increasing the pressure, it will be found that the assembly will assume the general appearance of a pillow. If properly welded, a high pressure must be applied before failure occurs, and it will then fail by opening along a line parallel to and within the weld area. At the point of failure, the metal will be bent at an angle of approximately 90 degs. We have welded two pieces of .024" stainless steel, two inches wide by 12 inches long, and applied 3000 lbs. per square inch water pressure without leaks or failure of the sample.

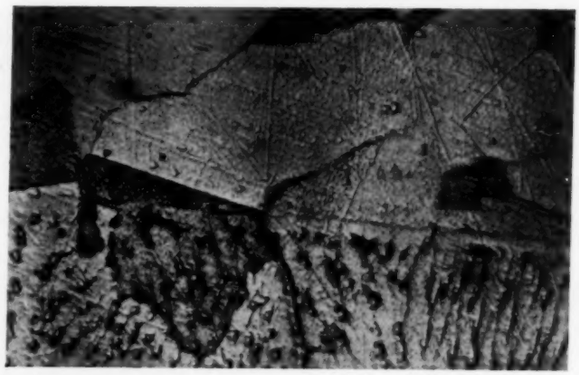
Naturally, the application of Thyratron control is not a cure for all the ills of resistance welding, but it has eliminated one of the most serious variables with which one has previously been forced to contend—the inaccuracies of control devices with respect to time of power application. The proper application of Thyratron control will open fields for resistance welding which have to date been untouched, and when applied to resistance welding machines already in service, will insure welds of improved quality at greater and more economical speeds.

FIG. 8—Cross Sectional Micrographs of Spot Weld on Two Sheets of .037 Annealed Stainless Steel (18-8).



(A) Weld Area Magnified 50 Dia.

(B) Fusion Line of the Two Sheets Magnified 1,200 Dia.



(C) Boundry Between Parent Metal and Fused Metal Magnified 1,200 Dia.

Discussion

Discussion Presented by

Stanley Grand Girard, Electrical Supt., Sharon Steel Hoop Company, Sharon, Pa.
W. C. Hutchins, Industrial Engineering Dept., General Electric Co., Schenectady, N. Y.
D. I. Bohn, Electrical Engineer, Aluminum Company of America, Pittsburgh, Pa.
F. S. Balke, Factory Engineer, Wheeling Corrugating Company, Wheeling, W. Va.

Stanley Grand Girard: I would like to know how the small thyratron tube is used in conjunction with the large one; whether connected by relays, or how that was taken care of?

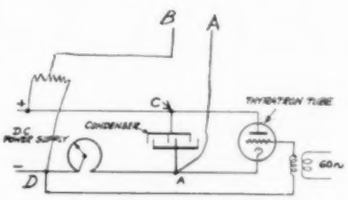
W. C. Hutchins: Where thyratron control is used for resistance welding, there are no mechanical relays whatever. As explained in the paper, the grids of the two large thyratron tubes short circuiting the

series transformer are controlled by an auxiliary circuit which produces a synchronously timed oscillating voltage in the following manner.

A condenser is charged with a direct current through a very high resistance. The voltage across the condenser gradually builds up until it reaches a peak voltage, at which instant a small thyratron tube connected properly in the circuit discharges the condenser to zero voltage. As soon as the condenser has been discharged, the small tube stops passing current in that there is zero potential across the anode and cathode of this small timing tube, the result being that the condenser begins charging again. The charging rate of the condenser can be varied by changing the amount of resistance through which the condenser must be charged, and by changing the capacity of the condenser being charged. The frequency of this oscillating circuit can, therefore, be varied greatly.

The alternating current voltage of the main power supply to the resistance welder is superimposed on the grid of the timing tube, causing the oscillations of this circuit to become synchronously timed with the alternating current power supply.

FIG. 9.



This timing circuit is schematically shown in Fig. 9. The direct current supply is approximately 220 volts. The potential across the condenser is practically zero at the instant the condenser begins to charge; therefore point "A" is the same potential as point "C", practically full line voltage drop occurring across the variable resistor. Under this condition, the cathode of the timing tube is the same potential as "A", and the grid is approximately 220 volts negative; therefore the tube will not pass current. The condenser gradually charges, building up the potential across the condenser until point "A" is approximately the same potential as point "D", or is about 200 volts negative with respect to "C". At this instant, the thyratron tube in the timing circuit begins passing current, since the cathode and grid are the same potential and the anode is positive. This discharges the condenser to zero voltage and the tube stops passing current, thus re-establishing "A" to the same potential as point "C". The condenser discharge is almost instantaneous. The condenser again begins charging and the cycle is repeated as long as the settings remain the same.

A resistor with mid tap "B" connected across points "C" and "D" gives a voltage at "B" 100 volts negative with respect to "C". Using "B" as a reference, the voltage of "A" is 100 volts positive when the condenser starts to charge, since the potential of "A" is equal to the potential of "C" at this instant. As the condenser charges, the potential of "A" decreases gradually until "A" is approximately 100 volts negative with respect to "B". At this instant; the small tube discharges the condenser, instantaneously re-establishing the potential of "A" to 100 volts positive with respect to "B".

The result is a gradual change in the potential of "A" from 100 volts positive to 100 volts negative with respect to "B", then a quick change re-establishing "A" at a potential 100 volts positive with respect to "B".

Now let us connect "A" to the grid of the large thyratron tubes which short-circuit the series transformer (shown in Fig. 3 of the paper being discussed) and connect "B" to the cathodes of these same tubes. The large tubes will conduct current as long as the grid (or point "A") is positive with respect to the cathode (or point "B"). The large tubes will stop passing current when the grid voltage (A) goes negative with respect to the cathode (B) and will prevent passage of current until the grid (A) again goes positive. This cycle of operation is repeated as long as all settings remain unchanged. By properly superimposing alternating current voltages on these various grid circuits, the complete operation becomes synchronously timed with the alternating current power supply.

The frequency of oscillations in the timing circuit depends upon the amount of resistance through which the condenser is charged. The ratio of "on" to "off" time depends upon adjustment of tap "B" on the resistor connected across the direct current supply. This explanation does not include all details of the timing circuit but gives you an idea of how the timing circuit is tied in with the large tubes.

D. I. Bohn: Our equipment has been in operation only a few days.

I would like to ask Mr. Hutchins whether or not a synchronous tube control method has been developed using a large number of small tubes in sequence, each one to handle one-half or one cycle.

W. C. Hutchins: Not to my knowledge; it seems feasible. Due to the excellent results, however, obtained with present designs, using only a few tubes in the timing circuit, it seems improbable that such a timer would be warranted. It would certainly cost a great deal more and would be no more flexible than the present type of timer.

D. I. Bohn: The equipment has operated beautifully, except that timing adjustments have not been completed. We have obtained as fine results as could be expected with line welding, and are just hooked up for spot welding, but have done very little of it with this equipment.

To weld aluminum, you have to melt the metal. When melted, aluminum has no strength. The ideal welding condition would be unlimited power capacity for an infinitely short period of time, which would mean the thermal transfer would be completely nullified, and the metal would be cold at the outside surfaces. With power on a machine 50% of the time or less, very good results are obtained on aluminum for line welding where thyratron control is used, and the duration of current application for each "on" period is kept to only a few cycles. Twenty-five per cent "on" time is what we have in mind as being the best welding condition with the power on for only one or two cycles. Above 50% "on" time will probably cause heat to reflect undesirable characteristics on the outside surfaces of the aluminum.

F. S. Balke: We have done some seam and spot welding but have never used control. Our first

machines had mechanically operated interrupters and it took us about two weeks to find out they were no good. We have been running for six or eight years without any interruption whatever except starting and stopping the machine. There are one or two things I would like to know. There used to be an idea the machine would work faster on seam welding; not quite as fast as with interrupter. We have a machine running on 19 gauge soft steel 41.7 in .42 of a minute. I believe that machine could be run 25% faster.

W. C. Hutchins: We must take into consideration the quality of welds when we speak of speeding up the operation. The maximum speed which we were able to obtain on 22 and 24 gauge stock was 15 feet per minute, and still get enough spots per inch to make a gas-tight joint under high pressure. If the pressure under which this seam operates was reduced, undoubtedly greater speeds than this could be obtained. On your work, which is on slightly heavier stock, possibly the very high quality joint is not required which, in a way, is apparent in that you do not at present interrupt the welding circuit. I feel confident in stating that your welding speed could be increased 25% or more, provided thyratron control were used to interrupt the welding circuit and confident that you would be able to get even higher quality welds than you now obtain without interrupting the circuit.

F. S. Balke: We have been welding 14" along the seam, 24 gauge, and average production was 500 seams an hour. We have run 600 and better, including time of being picked up by the workman, laying it down and picking up the next one. We do run some at 15 pieces a minute.

I have no idea how strong our welds are. We are manufacturing containers, the heads and bottoms of which are put in with a mechanical double seam. The welds are always stronger than the double seam. We have made hydraulic tests on these of probably 100 pounds per sq. in. pressure. The heads and bottoms of these always pull out without disturbing the welded seam.

ITEMS OF INTEREST

PERSONNEL CHANGES

▲

Mr. J. H. Van Campen, formerly with the Republic Steel Corporation as chief engineer of the Youngstown district, is now associated with the United Engineering & Foundry Company, Pittsburgh, Pa. Mr. Van Campen was an active member of the Association of Iron & Steel Electrical Engineers and has served as director at large and as treasurer of

J. H. VAN CAMPEN

this organization. He has presented many valuable papers and discussions before this society and has served the Association on many of its major and national committees.

The Association of Iron & Steel Electrical Engineers extends to him their best wishes in his new capacity.

Mr. G. L. Fisk is now associated with Blaw-Knox Company as assistant to the vice president. Mr. Fisk's experience in the field of steel mill engineering, design and construction has been exceptionally wide and varied. Before becoming associated with Blaw-Knox Company, Mr. Fisk was chief engineer of the Mesta Machine Company.

▲

Mr. Fred Waldorf is now associated with the Bantam Ball Bearing Company, South Bend, Ind. and will represent them in the Pittsburgh district with headquarters at 119 Gould Ave., N. S., Pittsburgh. Mr. Waldorf is the author of many valuable treatises covering anti-friction bearings. The Association wishes him success in his new capacity.

▲

Rudolph Furrer, formerly chief engineer and director of research for the A. O. Smith Corpn., Milwaukee, and also engineer for the Allis-Chalmers Mfg. Co., Milwaukee, has been appointed assistant to the operating vice presidents of the National Tube Co., Pittsburgh, and will be engaged in further extending their research and engineering studies.

OBITUARIES

Thomas A Beattie, general superintendent of the National works, McKeesport, Pa., of the National Tube Co., Pittsburgh, died at Pittsburgh, Feb. 26. He had been injured in an automobile accident at Pittsburgh, Feb. 21. Mr. Beattie was a native of Pittsburgh and had been with the National Tube Co. for approximately 50 years. He had been general manager of the Riverside works, Wheeling, W. Va., previous to his transfer to McKeesport.

▲

Thomas P. Davies, a former chief engineer of the Duquesne works of the Carnegie Steel Co., Pittsburgh, died at Duquesne, Pa., March 1. Mr. Davies had been a resident of Duquesne since 1886 and prior to his retirement had been affiliated with the Carnegie Steel Co. for 42 years.